

PREFACE

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INTRODUCTION

Properly designed and operated utilities are vital to a modern military installation. They are essential in safeguarding health, providing comfort, and promoting the general efficiency of all personnel.

As an engineer officer you may be assigned the job of directing some phase of utilities work. To do this efficiently, you must understand the broad, general phases of utilities operations. That is the purpose of this subcourse. It is planned to give you basic knowledge in utilities layout, installation, and operation.

Since much of the operation and maintenance of utilities are performed by engineer service teams, or detachments, information is also furnished on these organizations and their function.

This subcourse consists of seven lessons and an examination as follows:

Lesson 1. Organization and Functions of Utilities Engineer Service Teams.

2. Electric Power Systems.
3. Refrigeration Systems.
4. Water Supply and Distribution Systems.

5. Plumbing Installations and Bills of Materials.

6. Sewerage Systems.

7. Rehabilitation of Utilities.

Examination.

You will not be limited as to the number of hours you may spend in the solution of the subcourse, any lesson, or the examination.

Twenty credit hours are allowed for this subcourse.

The format of this subcourse has been changed to facilitate student selfpacing and to eliminate the necessity of submitting to the USAES each lesson answer sheet for grading. Each lesson in this subcourse is followed by a number of questions and exercises designed for a review of that lesson. After completing study of the lesson, you should answer these questions in the space provided below each, then turn to the back of the subcourse booklet where the correct answers have been included. A comparison of your answers with those given in the back of the subcourse will indicate your knowledge and understanding of the material presented.

*** * * IMPORTANT NOTICE * * ***

THE PASSING SCORE FOR ALL ACCP MATERIAL IS NOW 70%.

PLEASE DISREGARD ALL REFERENCES TO THE 75% REQUIREMENT.

LESSON 1

ORGANIZATION AND FUNCTIONS OF UTILITIES ENGINEER SERVICE TEAMS

CREDIT HOURS 1
TEXT ASSIGNMENT. Attached memorandum.
MATERIALS REQUIRED None.
LESSON OBJECTIVE Upon completion of this lesson on Engineer Service Teams you should be able to accomplish the following in the indicated topic areas.

1. **Purpose.** State in general terms, the purpose and functions of the utilities engineer service teams.
2. **Characteristics.** Give the five general characteristics which would be applicable to all utilities engineer service teams.
3. **Assignment.** Explain the various methods of team assignment and the responsibilities for team support.
4. **Capabilities.** By reference to the textual material provided, explain the capabilities of each team including qualification of personnel assigned and major items of equipment.
5. **Team selection.** Select the appropriate team for a specific requirement.

ATTACHED MEMORANDUM

1-1. INTRODUCTION

Within the military, utility services have been specialized and organized into engineer service teams. The Engineer Service Organization provides cellular, specialized teams of varying sizes, functions, and capabilities for use when standard organizations are too large or cannot meet the particular engineer needs of the theater of operations. The team organizations provide variety and flexibility to permit the most efficient use of manpower and equipment. Teams may be combined to form a composite platoon or company, depending on the nature and scope of the mission. Individual teams may be attached or assigned to an engineer unit to increase the unit's capabilities, or to a unit of another arm or service such as an Area Support Command, to provide a particular, required engineer capability.

Teams fall into the following eight classes:

- a. Administrative and headquarters.
- b. Firefighting.
- c. Equipment operating.
- d. Construction, utilities, and electrical power.
- e. Topographic and intelligence.
- f. Dredging.
- g. Engineer civic action.
- h. Engineer combat support.

1-2. CHARACTERISTICS

Teams have the following characteristics:

a. They comprise a group of individuals trained to work together as specialists in some particular field.

b. They may perform certain operations as a unit; comprise a specialized cadre around which a larger organization is built; or act as individual inspectors, instructors, or supervisors.

c. Their equipment is generally restricted to vehicles required to transport team personnel and materiel, individual weapons, and tools and supplies related to their specialty.

d. They are not self-sufficient in such matters as administration, shelter, messing, supply, storage facilities, signal communications, and medical service. For such support they must rely on the organization to which they are attached.

e. Some teams consist of only a handful of specialists, while others, such as certain topographic and equipment operating teams, are small-scale replicas of corresponding larger units.

1-3. MISSION OF ENGINEER CELLULAR TEAMS

a. To provide engineer technical, combat service, and combat support where units of less than company size are required.

b. To increase the capability of fixed strength units where increments of less than company size are required. These teams are designed to provide special support and will be assigned in accordance with the tactical and logistical considerations involved.

c. To provide command and administrative personnel for engineer composite units.

d. To provide advisory assistance to host country forces and units in an internal defense and development operational environment.

1-4. ASSIGNMENT

Teams may be attached or assigned as required to fixed strength units or may be organized into a separate composite unit.

1-5. CAPABILITIES

a. The capabilities of an individual team are listed in the discussion of that team. The capabilities of an engineer composite unit of several teams will vary with the number and types of teams used.

b. Most of these teams must be furnished supply, mess, administrative, personnel, medical, signal, and organizational maintenance services. These are ordinarily provided by the fixed strength unit to which a team is assigned or attached. When applicable, mess teams will be drawn from the TOE 29-500 series, automotive maintenance teams from the TOE 29-600 series, and personnel services will be provided by an AG personnel service unit or a support team drawn therefrom. A composite unit formed from two or more teams may be commanded and provided administrative services by: (1) Team AB, platoon headquarters, separate to provide personnel and equipment for the headquarters of an engineer platoon formed from two or more teams of the TOE 5-500 series, or (2) team AC, company headquarters, to provide personnel and equipment for the headquarters of a company-sized unit formed from two or more teams of the TOE 5-500 series.

c. These teams are not adaptable to level 2 or 3 strengths nor to a type B organization. However, host country or allied nationals may in some cases be used to supplement team strength.

d. Individuals of these teams can engage in effective coordinated defense of the team's area or installation, or contribute to the defense of the unit to which assigned or attached.

1-6. BASIS OF ALLOCATION

The allocation of teams depends on the special support requirements. Type allocations are indicated in the discussion of individual teams.

1-7. CATEGORY

The category given each team is based on the area of employment of the units to which

the team is normally assigned (reference Unit Categories, AR 320-5).

1-8. MOBILITY

The degree of mobility utilizing organic transport is given for each team. When teams are combined to form a composite unit, the mobility of the composite unit must be computed.

1-9. ENGINEER INSTALLATION SUPPORT

a. **In the COMMZ.** Engineer installation support in the communications zone is provided by cellular teams of the 5-500 series of TOE's. Teams are assigned to Area Support Groups (ASGP) of the Area Support Command (ASCOM). Area Support Groups are assigned areas of responsibility to provide direct combat service support (including installation support) to the TASCOM commands and other designated forces in the COMMZ. The assigned teams provide the following services:

- (1) Operation, maintenance, and repair of utilities, including sewage and trash disposal and water supply.
- (2) Maintenance, report, and minor new construction of all types of facilities.
- (3) Fire protection service.
- (4) Real estate service.

b. **In the combat zone.** Engineer installation support in the combat zone is provided for the corps support command (COSCOM) by teams of the 5-500 series of TOEs. This support consists of real estate, facilities engineering, and firefighting services. Teams are attached to, and under the command and control of, the COSCOM or its subordinate units.

1-10. ENGINEER EQUIPMENT OPERATING TEAMS, TOE 5-520G

TOE 5-520G consists of teams of various sizes and types whose mission is to provide engineer equipment operating teams for support to the Army as required. Paragraphs 1-11 through 1-16 below provide information on teams in TOE 5-520G that are concerned with the supply of water.

1-11. TEAM GE, WELL DRILLING

a. **Capability.** Capable of drilling and developing water wells on a two-shift

basis. Installs casings, screens, and pumps to supply water to users at the well head.

b. **Basis of allocation.** Normally attached to an engineer construction or combat unit to provide support for drilling operations.

c. **Category.** II.

d. **Mobility.** 100 percent mobile.

e. **Strength.** Aggregate--5, as follows:

Number	Grade	MOS
1	E-6 (NCO)	62N40
1	E-6	62J30
2	E-5	62J30
1	E-4	62J30

f. **Major items of equipment.**

Weapons

Individual weapons only.

Vehicles

Semitrailer, tank, water, 2000 gal ...	1
Truck, cargo, 3/4-T	1
Truck, cargo, 5-T	1
Truck, Tractor, 5-T	1

Other Equipment

Drilling machine, well, rotary, trlr mtd, DED, 5-7/8 in dia at 1500 ft	1
Tool kit, pipefitter's	1
Torch outfit, cutting and welding	1

g. **Method of operation.** Team personnel reconnoiter an area and select one or more well sites. Work is scheduled in two or more shifts so that the well drilling operation is continuous. The supported unit provides one or more helpers for each shift and must supply all casings, screens, and pumps required. Engineer work at the site -- clearing, access roads, and a parking area -- is performed by the supported unit. For de-tailed information on well drilling operations, see TM 5-297.

1-12. TEAM GF, WELL DRILLING (AIRBORNE)

a. **Capability.** Capable of developing and drilling water wells. On a two-shift basis in-

stalls casings, screens and pumps, and develops drilled wells to supply water at the water head. May drill blast holes up to 4-7/8 inch in diameter and up to 500 feet deep for quarrying or to create obstacles and barriers. Supported unit must provide helper personnel for effective utilization of the team.

b. Basis of allocation. Normally attached to an engineer combat battalion, airborne, or to the airborne division engineer battalion. May be attached to the engineer light equipment company, airborne.

c. Category. II.

d. Mobility. 100 percent mobile.

e. Strength. Aggregate--5, as follows:

Number	Grade	MOS
1	E-6	62N4P
1	E-6	62J3P
2	E-5	62H3P
1	E-4	62J3P

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Trailer, low bed, 8-T	1
Truck, cargo, 3/4-T	1
Truck, cargo, 5-T	1
Truck, tank, water, 1000 gal, 2½-T	1

Other Equipment

Drilling machine, rotary, skid mtd, GED, 4-7/8 inch diameter hole at 600 foot depth	1
Tool kit, pipefitter's	1
Torch outfit, cutting and welding	1

g. Method of operation. Work is scheduled in two or more shifts so that the well drilling operation is continuous. The supported unit provides one or more helpers or each shift. If the team and its drilling equipment are air dropped, the supported unit provides equipment to move the drill rig to the drilling site. Engineer work at the well site--clearing, access roads, and a parking area--is performed by the supported unit. For detailed information on well drilling operations, see TM 5-297.

1-13. TEAM GG, WATER PURIFICATION (3,000 GPH)

a. Capability. Capable of producing up to 3,000 gallons of potable water per hour and storing up to 9,000 gallons.

b. Basis of allocation. Normally attached to an engineer unit having a large water supply mission or to an area support group.

c. Category. II.

d. Mobility. 100 percent mobile.

e. Strength. Aggregate--4, as follows:

Number	Grade	MOS
1	E-5 (NCO)	51N40
3	E-4	51N20

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Truck, cargo, 3/4-T	1
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Other Equipment

Generator set, 10 kw	2
Ion exchange unit, water purification, trk mtd	1
Tank, 3,000 gal, fabric, collapsible	3
Telephone set, TA-312/PT	1
Water purification equipment set, trk mtd, 3,000 gph	1
Water quality control set	1

g. Method of operation. Team personnel reconnoiter for and select a suitable site for the establishment of a water point. Engineer work at the water point -- clearing, access roads, turn-arounds, and a parking area -- is performed by the supported unit. Wire communication to the water point, when necessary, is installed by the supported unit. Security of the water point beyond the capability of the team is provided by the supported unit. For details of water purification operations, including the treatment of water contaminated with chemical, biological, and radiological (CBR) agents, see TM 5-700.

1-14. TEAM GH, WATER PURIFICATION (12,000 GPH)

a. Capability. Capable of operating single or multiple standard water purification

units forming a central field water plant to support 6,000 to 60,000 individuals.

b. Basis of allocation. Normally attached to an engineer unit, such as a brigade or group, which has a large water supply mission or an area support group. May be attached to a military government team.

c. Category. III.

d. Mobility. 100 percent mobile.

e. Strength. Aggregate -- 17, as follows:

Number	Grade	MOS
1	LT	4940
1	E-6 (NCO)	51N40
4	E-5 (NCO)	51N40
9	E-4	51N20
2	E-4	51N20

f. Major items of equipment

Weapons

Individual weapons only.

Vehicles

Trailer, cargo, 3/4-T 1
Truck, cargo, 3/4-T 1

Other Equipment

Generator set 1.5 kw 1
Generator set 10 kw 5
Ion exchange unit, water purification,
trk mtd 1
Light set, general illuminating, 25 outlet
..... 1
Pump 65 gpm 8
Pump 125 gpm..... 4
Tank, 3,000 gal, fabric collapsible 12
Telephone set TA-312/PT 4
Tool kit, pipefitter's 1
Water purification equipment set,
trk mtd, 3,000 gph 4
Water quality control set 4

g. Method of operation. Team personnel reconnoiter for and select a suitable site for the establishment of a central field water plant. Individual water purification units (up to four) are connected to a single central distribution point. Engineer work at the water point is performed by the supported unit. Wire communication to the water point, when necessary, is installed by the supported unit. Security of the water point beyond the capability of the team is provided by

the supported unit. For details of water purifications, including the treatment of water contaminated with CBR agents, see TM 5-700.

1-15. TEAM GI, WATER DISTILLATION (250 GPH)

a. Capability. Capable of producing 5,000 gallons of potable water per day using sea or brackish water operating on a two-shift basis (20 hours).

b. Basis of allocation. May be attached to any size unit or assigned to a civic action mission on an as required basis.

c. Category. III.

d. Mobility. 100 percent mobile.

e. Strength. Aggregate -- 6, as follows:

Number	Grade	MOS
2	E-5 (NCO)	51N40
4	E-4	51N20

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Truck, cargo, 2 1/2-T 2

Other Equipment

Distillation equipment set, water, thermo-compression, trlr mtd 150 GPH 2
Pump, 65 gpm 4
Water quality control set 2

g. Method of operation. Team personnel reconnoiter for and select a suitable site for a water point. Engineer work at the water point; clearing, access roads, turnarounds, brine sumps, and a parking area is performed by the supported unit. For information on water distillation and on the treatment of water contaminated with CBR agents, see TM 5-700.

1-16. TEAM GJ, WATER TRANSPORT (5,000 GAL)

a. Capability. Capable of transporting water for short hauls of 10 to 15 miles to dry water points. Capable of transporting 5,000 gallons of water per trip.

b. Basis of allocation. Normally attached to an engineer unit or an area support group with a water hauling requirement.

c. Category. II.

d. Mobility. 100 percent mobile.

e. Strength. Aggregate--8, as follows:

Number	Grade	MOS
2	E-4	64A10
6	E-3	64A10

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Truck, tank, water, 2 ½-T, 100 gal .. 5

g. Method of operation. Team hauls potable water from a water source to a distribution point or non-potable water to support a large concrete construction project.

1-17. ENGINEER CONSTRUCTION, UTILITIES, AND ELECTRICAL POWER TEAMS, TOE 5-530G

TOE 5-530G consists of teams of various sizes and types whose mission is to provide engineer construction and facilities engineering teams for specialized support to the Army as required. Paragraph 1-18 through 1-24, below, provide information on some of the teams in TOE 5-530G.

1-18. TEAM HB, PIPELINE DESIGN

a. Capability. Capable of assisting the supported unit in:

(1) Reconnaissance and selection of sites for major tank farms, pipeline routes and appurtenant structures, offshore discharging and loading facilities, and fixed dispensing equipment.

(2) Design and layout of pipeline projects, preparation of specifications and construction estimates, selection of material and equipment, and formulation of a construction plan.

(3) Management and supervision of construction operations.

b. Basis of allocation. Normally to an engineer construction group on an as-required basis.

c. Category. III.

d. Mobility. 100 percent mobile.

e. Strength. Aggregate -- 6, as follows:

Number	Grade	MOS
1	LTC	7932
1	CPT	7932
1	E-7 (NCO)	51F40
1	E-6	81B20
1	E-4	71B30
1	E-4	81B20

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Trailer, cargo, 1 ½-T	1
Trailer, cargo, 3/4-T	1
Truck, cargo, 3/4-T	1
Truck, utility, ¾-T	1

Other Equipment

Drafting equipment set, bn	2
Interpretation kt, photographic .	1
Sketching set, survey	1
Stereoscope lens, aerial photo interpretation	1
Stereoscope prism-mirror	1

g. Method of operation. Team works closely with engineer units engaged in pipeline construction rehabilitation. It provides assistance and supervision in all phases of a project from initial survey through actual construction operations and with petroleum staff elements and units responsible for planning and operating these facilities. For details on pipeline design and construction, see TM 5-343.

1-19. TEAM HC, REAL ESTATE

a. Capability. Capable of performing functions incidental to acquisition, utilization and disposal of real property required or occupied by military forces.

b. Basis of allocation. Normally one per Corps Support Command, and/or Area Support Command.

c. Category. III.

d. Mobility. 100 percent mobile.

e. Strength. Aggregate -- 16, as follows:

Number	Grade	MOS
1	MAJ	4312
1	CPT	4312
3	LT	4312
1	E-8 (NCO)	51H50
2	E-6	51H40
1	E-6	71D20
4	E-4	71B30
1	E-4	84B20
2	E-3	70A10

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Trailer, cargo, 7-T	2
Trailer, cargo, 3/4-T	1
Truck, cargo, 3/4-T	2
Truck, utility, 7-T	3

Other Equipment

Camera set, still picture	1
Gen set, 3 KW	1
Photocopying and processing machine	1
Photographic set, printing and processing, ES-28	1
Reproduction set, diazotype machine, moist process	1
Reproduction expendable supply set, moist process	1

g. Method of operation. The team prepares real estate acquisition and disposal documents and inventories and records the location, extent, and condition of real property required or occupied by Army forces. The team commander and his deputy are contracting officers for real estate functions. The deputy also appraises or secures appraisals of real property and reviews and approves rental agreements and damage and restoration estimates. The other officers are responsible for negotiation and preparation of leases, licenses, termination agreements, and disposal documents, and for the investigation and processing of claims connected with real estate operations. For information on real estate operations, see TM 5-300.

1-20. TEAM HE, UTILITIES (2,500)

a. Capability. Capable of providing facilities engineering type services for an overseas or theater of operations installation with a population up to 2,500. Maintains and repairs buildings, roads, and utilities including refrigeration.

b. Basis of allocation. Normally to the Corps Support Command on the basis of one per camp, base, depot, or other installation with a population up to 2,500.

c. Category. III.

d. Mobility. 95 percent mobile.

e. Strength. Aggregate -- 31, as follows:

Number	Grade	MOS
1	CPT	7130
2	E-6 (NCO)	51P40
1	E-5	82B20
1	E-5	62K20
1	E-5	62M20
1	E-5	51B20
1	E-5	51K20
2	E-4	62J20
1	E-4	44D20
3	E-4	51B20
3	E-4	51R20
2	E-4	62B20
1	E-4	81A10
2	E-4	64B20
3	E-4	51K20
1	E-4	51L20
1	E-4	44C20
1	E-4	63B20
3	E-3	51A10

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Trailer, cargo, 7-T	1
Truck, cargo, 3/4-T	3
Truck, dump 5-T	2
Truck, utility, 7-T	1

Other Equipment

Drafting equipment set, bn	1
Generator set, 3 kw.....	1
Grader, road. mtzd, DED 6 x 4 ...	1

Loader, scoop, 2 ½ cu yd 1
 Pneumatic tool and compressor outfit,
 250 cfm, trailer mtd..... 1
 Rod, level 1
 Rod, stadia 1
 Roller, motorized, GED, 3-wheel 10-T 1
 Spray outfit, paint, 2 guns, w/compressor
 1
 Tool kit, blacksmith's 1
 Tool kit, carpenter's 4
 Tool kit, electrician's, set No. 1 . 3
 Tool kit, pioneer, engineer platoon. 1
 Tool kit, pipefitter's, 1/8 to 2 in. pipe
 1
 Tool kit, pipefitter's, 2 ½ to 4 in. pipe
 1
 Tool kit, service, refrigeration ... 1
 Tool kit, sheet metal worker's 1
 Tool kit, welder's 1
 Tool outfit, pioneer, portable
 electronic tools..... 1
 Transit, 1 minute 16 to 21 diam.
 magnifying power..... 1
 Welding shop, trlr mtd 1
 Welding set, arc, inert gas shielded 1

g. Method of operation. Team functions in a manner similar to that of a facilities engineering organization at a CONUS installation. The team leader acts as the facilities engineer; team members repair and maintain utilities services, structures, and roads, and do minor new construction within the team's capability. For details on facilities engineering, see the TM 5-600-series.

1-21. TEAM HF, UTILITIES (4,000)

a. Capability. Capable of providing for maintenance of utilities at installations of from 2,500 to 4,000 individuals; provide facilities engineering type service in overseas or theater of operations installations; maintain utilities and furnish utilities service and repair, including maintenance of environment equipment (air conditioners, heaters, and refrigeration equipment). Specialized tools and equipment required to carry out the repair and utility functions described above must be provided by the installation or activity supported, under the provisions of AR 385-32.

b. Basis of allocation. Normally to the Corps Support Command of TASCOT and/or

the Engineer Command on the basis of one per camp, base, depot, or other installation with a population of 2,500 to 4,000.

c. Category. III.

d. Mobility. 95 percent mobile.

e. Strength. Aggregate -- 52, as follows:

Number	Grade	MOS
1	CPT	7130
1	WO	521AO
1	E-7 (NCO)	51P40
1	E-6 (NCO)	51H40
1	E-6 (NCO)	51P40
1	E-5	82B20
1	E-5	62K20
1	E-5	62M20
1	E-5	64B20
2	E-5	51B20
1	E-5	52F20
1	E-5	51K20
2	E-4	62J20
1	E-4	44D20
8	E-4	51B20
3	E-4	51R20
1	E-4	62B20
1	E-4	81A10
3	E-4	51J30
2	E-4	64B20
4	E-4	51K20
2	E-4	51L20
3	E-4	51J20
1	E-4	76P20
1	E-4	44C20
1	E-4	63B20
4	E-3	51A10
1	E-3	52A10
1	E-3	70A10

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Trailer, cargo, 7-T 1
 Trailer, cargo, 3/4-T 2
 Truck, cargo, 3/4-T 3
 Truck, dump, 5-T 3
 Truck, utility, 7-T 1

Other Equipment

Drafting equipment set, bn	1
Generator set, 3 kw	1
Grader, road mtzd, DED, 6 x 4	1
Loader scoop, 2 ½ cu yd	1
Pneumatic tool and compressor outfit, 250 cfm, trlr mtd	1
Pump, centrifugal, GED, frame, mtd, 170 gpm, 50 ft head	1
Rod, level	1
Road, stadia	1
Roller, motorized, GED, 3-wheel, 10-T	1
Spray outfit, paint, 2 guns, w/compressor	1
Tool kit, blacksmith's	1
Tool kit, carpenter's	10
Tool kit, electrician's, set No. 1	4
Tool kit, pioneer, engineer platoon	2
Tool kit, pipefitter's, 1/8 to 2 in pipe	4
Tool kit, pipefitter's, 2 ½ to 4 in pipe	1
Tool kit, service, refrigeration .	1
Tool kit, sheet metal worker's ...	3
Tool kit, welder's	1
Tool outfit, pioneer, portable electric tools	1
Torch outfit, cutting and welding, set No. 3	1
Transit, 1 minute 16 to 21 diam. magnifying power	1
Welding set, arc, inert gas shielded	1
Welding shop, trlr mtd	1

g. Method of operation. Team functions in a manner similar to that of a facilities engineering organization at a CONUS installation. The team leader acts as the facilities engineer; team members repair and maintain utilities services, structures, and roads; and do minor new construction within the team's capability. For details on repairs and utilities, see the TM 5-600 series.

1-22. TEAM HG, UTILITIES (10,000)

a. Capability. Provides for maintenance of utilities at installations of from 4,000 to 10,000 individuals; provides facilities engineering type service in overseas or theater of operations installations; maintains utilities and furnishes utilities service and repair, including maintenance of

environmental equipment (air conditioners, heaters, and refrigeration equipment). Additional tools and equipment required to carry out the repair and utility functions described herein must be provided by the installation or activity supported, under the provisions of AR 310-34 and/or AR 385-32.

b. Basis of allocation. Normally on the basis of one team for each camp, post, depot, or other installation with a population of 4,000 to 10,000.

c. Category. III.

d. Mobility. 85 percent mobile.

e. Strength. Aggregate -- 90, as follows:

Number	Grade	MOS
1	LTC	7130
1	CPT	7130
1	LT	7020
1	WO	521A0
1	E-8 (NCO)	51H50
1	E-7 (NCO)	51H40
1	E-7 (NCO)	41P40
1	E-7 (NCO)	62N40
1	E-6 (NCO)	62B40
1	E-6 (NCO)	76Y40
1	E-6 (NCO)	51P40
1	E-6	81B20
1	E-5 (NCO)	51N40
1	E-5	82B20
1	E-5	71H20
2	E-5	52G20
1	E-5	44E20
2	E-5	62D20
2	E-5	51B20
1	E-5	62H20
1	E-5	62E20
1	E-5	51R20
3	E-5	62K20
2	E-5	64B20
2	E-5	51K20
1	E-5	44C20
2	E-4	62J20
1	E-4	76Y20
2	E-4	62D20
1	E-4	71B30
1	E-4	62F20
1	E-4	81B20
4	E-4	52F20
2	E-4	62B20
1	E-4	71T20
8	E-4	51B20
1	E-4	51J30

4	E-4	64B20
2	E-4	62M20
2	E-4	51D20
1	E-4	72B20
1	E-4	76V20
7	E-4	51K20
2	E-4	51L20
1	E-4	76Q20
1	E-4	51J20
1	E-4	44C20
1	E-4	63B20
1	E-4	62L20
2	E-3	51A10
1	E-3	52A10
1	E-3	62B10
5	E-3	51A10

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Semitrailer, low bed, 2-T, 4 wheel ..	1
Truck, cargo, 3/4-T	3
Truck, cargo, 2 ½-T	1
Truck, dump, 5-T	6
Truck lift fork 6000 lb rough terrain	1
Truck, tractor, 10-T	1
Truck, utility, ¾-T	1

Other Equipment

Book set, const gp	1
Crane shovel, crawler mtd, 12½-T, 3/4cu yd	1
Distributor, bituminous material, truck mtd, 800 gal	1
Distributor, water, truck mtd, 1000 gal	1
Drafting equipment set, bn	1
Generator set, 3 kw	3
Generator set, 5 kw	1
Generator set, 10 kw.....	1
Grader, road, motorized, 6 x 4	2
Kettle, heating, bitumen, trailer mtd, 165 gal	2
Loader, scoop, 2 ½ cu yd	1
Mixer, concrete, trailer mtd, 16 cu ft	1
Roller, motorized, 3 whl, 10-T	1
Scraper, earth moving, grader mounting	2
Service kit, power line maint	1
Shop equip, woodwork, base maint, trlr mtd	1
Survey set, gen purp	1
Tool kit, carpenter's.....	6
Tool kit, electrician's set No. 1 ...	5

Tool kit, mason and concrete finisher's	1
Tool kit, pioneer, engr platoon	3
Tool kit, pipefitters 1/8 to 2 in pipe	9
Tool kit, pipefitter's, 2½ to 4 in pipe	1
Tool kit, service, refrigeration	2
Tool kit, sheetmetal worker's	2
Tool outfit, pioneer portable elec tools	3
Tractor, airmobile, w/backhoe and front loader, ½ cu yd	1
Tractor, tracked, med DBP	1
Welding set arc, inert gas shield	1
Welding shop, trlr mtd	1

g. Method of operation. Team functions in a manner similar to that of a facilities engineering organization at a CONUS installation. The team leader acts as the facilities engineer; team members repair and maintain utilities services, structures, and roads; and do minor new construction within the team's capability. For details on repairs and utilities, see the TM 5-600-series.

1-23. TEAM HH, POWER PLANT OPERATION AND MAINTENANCE

a. Capability. Capable of operating and maintaining an electric power plant containing from one to three diesel engine generators of 300 to 2,500 kw capacity.

b. Basis of allocation. Normally one per Engineer Construction Brigade.

c. Category. III.

d. Mobility. 60 percent mobile.

e. Strength. Aggregate -- 16, as follows:

Number	Grade	MOS
1	LT	7611
1	E-6 (NCO)	52E40
1	E-5	52G20
2	E-5	52E20
2	E-5	52B30
3	E-4	52E20
4	E-4	52B30
2	E-3	52A10

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Trailer, cargo, 3/4-T	1
Truck, cargo, 3/4-T	1

Other Equipment

Multimeter, AN/USM-223	3
Service kit, power plant maint ...	1
Tool kit, automotive mechanic's...	6
Tool kit, carpenter's, engineer plat	1
Tool kit, electrician's, set No. 1	3
Tool kit, electronic equipment repair	1
Torch outfit, cutting and welding, set No. 3	1

g. Method of operation. Team is divided into two shifts to provide continuous operation of the power plant. For information on electric power in the field, see TM 5-766.

1-24. TEAM HJ, POWER LINE

a. Capability. Capable of installing high voltage electric power lines, including setting poles, and maintaining approximately 60 miles of high voltage electric power lines.

b. Basis of allocation. Normally one per two electric power generator plants of 300 to 2,500 kilowatt capacity.

c. Category. III.

d. Mobility. 100 percent mobile.

e. Strength. Aggregate -- 14, as follows:

Number	Grade	MOS
1	LT	7611
1	E-6 (NCO)	52G40
9	E-5	52G20
3	E-4	52G20

f. Major items of equipment.

Weapons

Individual weapons only.

Vehicles

Trailer, cable, reel, 3 ½-T	1
Trailer, cargo, 1 ½-T	1
Truck, cargo, 3/4-T	3
Truck, cargo, 2 ½-T	1
Truck, maintenance, earth borer, pole setter	1

Other Equipment

Multimeter, AN/USM-223	3
Tool kit, carpenter's, engineer plat	1
Tool kit, electrician's, set No. 1 ..	9
Tool kit, electronic equipment repair	10
Voltmeter, portable	1

g. Method of operation. Team may be divided into three sections, each responsible for the maintenance and repair of 20 miles of power line. For power line installation it is advisable to augment the team with personnel for setting poles. For information on electric power transmission and distribution, see TM 5-765.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space provided below each question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in the back of this booklet. Review the lesson as necessary. Do not send in your solutions to these review exercises.

1. Give a brief, general description of utilities engineer service teams. (Para 1-1)

2. State a characteristic of the engineer service teams which broadly defines their training and utilization. (Para 1-2a)

3. How do these teams ordinarily obtain supply, mess, and medical services? (Para 1-5b)

4. When the mission requires the support of two or more engineer service teams, these teams may be formed into a composite unit. In this case, how are command and administrative services provided? (Para 1-5b)

5. How is engineer utility support provided to installations in a communications zone? (Para 1-9a)

6. What command, or organization, controls utilities engineer support teams operating in the combat zone? (Para 1-9b)

7. What is the most normal assignment for team GE, Well Drilling? (Para 1-11b)

8. What is the principle difference in the capabilities of teams GE and GF? (Paras 1-11f, 1-12f)

9. Team GG, Water Purification, selects a suitable site for establishment of a water point. Who builds the access roads to the site? (Para 1-13g)

10. What team is trained and equipped to convert sea or brackish water, to potable water? (Para 1-15a)

11. If you are commanding a construction unit on a project and a requirement for 10,000 gallons of water a day delivered from a source 15 miles away suddenly comes up, what engineer service team would you like to have available to you? (Para 1-16a)

12. What military unit does the team HB, Pipeline Design, normally support? (Para 1-18b)

13. Estimates of damage to land and crops by military units on a field exercise, are the responsibility of what particular individual? (Para 1-19g)

14. Where might you find detailed information on real estate operations? (Para 1-19g)

15. A Corps Support Command has four camps and one depot in its area of responsibility, each has a population less than 2,500. How many, and what type, utility teams would be authorized to this command? (Para 1-20b)

16. What is the aggregate strength of a utilities team capable of providing facilities engineering type service for an overseas installation of 3,500 population? (Para 1-21a)

17. How many vehicles are provided with team HG, Utilities? (Para 1-21a)

18. What special feature of its organization makes team HH, Power Plant Operation and maintenance, capable of continuous operations? (Para 1-23g)

19. How many miles of high voltage electric power line can be installed and maintained by team HJ, Power Line? (Para 1-24a)

20. How is team HJ, Power Line, transported from one site to another? (Para 1-24d)

LESSON 2

ELECTRIC POWER SYSTEMS

CREDIT HOURS 4
TEXT ASSIGNMENT. Attached memorandum.
MATERIALS REQUIRED None.
LESSON OBJECTIVE Upon completion of this lesson on Electric Power Systems you should be able to accomplish the following in the indicated topic areas.

1. **Basic concept of electricity.** Explain the basic concept of electricity including such terms as circuit, current, resistance, conductor, insulator, volt, watt, ampere, and ohm.

2. **Laws of electricity.** Apply the laws of electricity in the analysis of an existing or planned electric power system.

3. **Electric power system.** Explain the features of the two-wire, three-wire, and four-wire systems and give illustrations of the appropriate use of each.

4. **Series and parallel circuits.** Define series and parallel circuits covering the special features, advantages, and disadvantages of each, and give examples of the appropriate use of each.

5. **Transformers.** Describe the construction and use of transformers, the different transformer connections, transformer capacity, maintenance, location, and protection.

6. **Generators.** Describe types of generators, principles of operation, use, and maintenance.

7. **Motors.** Describe types, uses, care, maintenance, and efficiency of electric motors.

8. **Associated equipment and accessories.** Describe the various minor items of equipment and accessories such as wire, conduit, outlet boxes, cable, and insulation used in an electric power system.

9. **Layout and construction.** Design an electric power system for a theater of operations installation based upon knowledge of the power requirement and materials and equipment available. Design to include details of layout, connections, supports, bends, and other construction features.

10. **Safety.** Outline safety precautions to be observed when working with electrical power systems.

ATTACHED MEMORANDUM

2-1. GENERAL

This lesson covers the fundamentals, layout, and construction of electric power distribution, systems for theater of operations installations.

a. The two sources of electric power considered are portable military generators and existing plants supplying high-voltage power for military use.

b. Layouts of distribution systems are based on standard equipment supplied to over-seas depots.

2-2. BASIC CONCEPTS OF ELECTRICITY

Electricity is a form of energy which the electrician controls by proper installation of wires, switches, and devices to produce usable light, power, and heat. Electric energy is generated chemically as in a battery, or mechanically as in an electric generator.

a. **Flow of electricity.** When the terminals of a battery or generator are connected by a wire, electricity flows through the wire. The path of flow is called a circuit, and the electrical flow, a current. To use the current, an electrical device such as a lamp, heater, or motor is connected in the circuit and the electrical energy is changed to light, heat, or mechanical energy.

b. **Resistance.** Resistance is the opposition to electrical flow. Resistance increases as the length of wires is increased, and decreases as the cross-sectional area of wires is increased. Thus, resistance varies inversely with the cross-sectional area of the wire.

c. **Conductors and insulators.** Different materials resist the flow of electricity in varying degrees. For example, copper or aluminum, which have very little resistance, and iron, which has about six times the resistance of copper, are conductors. Materials which allow practically no current to flow, such as cotton, porcelain, and rubber, are insulators.

2-3. MEASURING ELECTRICITY

Pressure, flow, and power of electricity and resistance are measured and vary in quantity for various appliances. To furnish the required amount of electricity to a device safely and efficiently, the electrician must know the meaning of electrical units of measure.

a. **Volts.** Volts measure the "pressure" of electricity much the same way as pounds per square inch measure water pressure. The electromotive force which produces a

current of 1 ampere when steadily applied to a conductor having a resistance of 1 ohm is defined as a volt.

b. **Watts.** Watts measure the rate of flow of energy through the circuit at a given instant, the same as horsepower measures the energy developed by an engine.

746 watts = 1 horsepower

NOTE: Both watts and horsepower denote the rate of work being done; not the total work done.

c. **Kilowatts.** Kilowatts are convenient for expressing large wattages.

1,000 watts (w) = kilowatt (kw)

d. **Kilowatt hours.** The kilowatt hour (kwh) measures the total quantity of energy consumed in a given time.

Average kilowatts x hours = kilowatt hours.

e. **Ohms.** Ohms measure the resistance of material to the flow of electricity; the higher the number of ohms, the greater the resistance. A wire has a 1-ohm resistance if 1 ampere flows through it when it is connected to a 1-volt electrical source.

f. **Amperes.** Current is the flow of electrons and is measured in amperes. Ampere is analogous to the term "gallons per minute" used in hydraulics. The number of electrons passing a given point in the circuit per second is by definition the number of amperes of current flow.

2-4. LAWS OF ELECTRICITY

To simplify the explanation of laws of electricity, direct-current fundamentals will be used to explain Ohm's law, power, voltage drop, and power loss.

a. **Ohm's law.** When 1 volt forces 1 ampere through a wire with a given resistance, 5 volts will force 5 amperes through the same wire at the same resistance. In other words, when resistance is constant, current is in direct proportion to voltage. The Ohm's law can be expressed by the following formula:

$$\text{OHMS} = \frac{\text{Volts}}{\text{Amperes}}$$

For brevity, the formula is set up in symbols.

$$R = \frac{E}{I}$$

$$R = \frac{E}{I}$$

or: Where: I = AMPERES

$$I = \frac{E}{R}$$

$$I = \frac{E}{R}$$

$$I = \frac{E}{R}$$

or :

$$E = IR$$

Derived facts from Ohm's law:

(1) If any two factors are known, the third can be computed.

(2) If the voltage is constant, amperes may be increased by decreasing the resistance.

(3) If resistance (size, length, and material of wire) is constant, increasing the voltage increase the amperage.

(4) If amperage is constant, increasing the size of wire reduces resistance and permits use of lower voltage.

b. Power. Electric power (P) is measured in watts and can be converted to horse-power (hp).

$$P = EI = I^2R \text{ (WATTS)}$$

$$HP = \frac{EI}{746} = \frac{I^2R}{746} \text{ (HORSEPOWER)}$$

c. Voltage drop and power loss.

(1) Voltage drop is electrical pressure lost as current flows through a wire or an electrical device: A voltmeter, used to measure voltage, connected between terminals A and B shows that the power source is producing 115 volts; one connected between C and D shows that the lamp is using 110 volts to produce light (fig. 2-1). The 5-volt difference in meter readings measures the voltage drop in the line and can be compared to the loss of pressure caused by friction in a long water pipe. Voltage drop in the conductor can be computed using Ohm's law, if current and resistance of the conductor are known. To furnish satisfactory voltage to equipment and

to keep power losses low, voltage drop in the line must be kept low.

$$E = IR$$

VOLTAGE DROP

$$P = I^2R$$

POWER LOSS

(2) To reduce power loss and voltage drop:

- (a) Use large size wires.
- (b) Use high voltage.
- (c) Keep distribution

distances (distance between generator and fixtures) as short as possible.

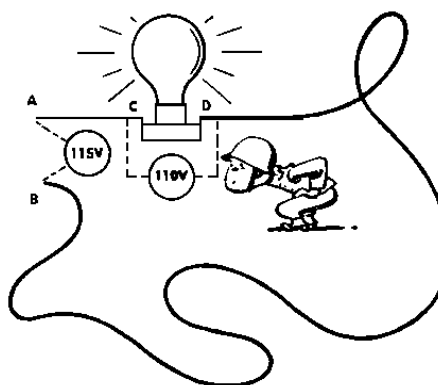


Figure 2-1. Voltage drop.

2-5. CURRENT

a. Direct current. Direct current (dc) flows continually in one direction. When terminals of a battery or generator are marked (+), P, or POS (positive), and (--), N, or NEG (negative), the current produced by connecting the terminals is direct current. Current from a battery is always direct current.

b. Alternating current.

Alternating current (ac) is a current that reverses its direction of flow at regular intervals.

(1) A simple alternating-current generator consists of a rotating magnet and a coil of wire. As the north pole (N) of the magnet passes the coil, a voltage is generated and current flows (fig 2-2).

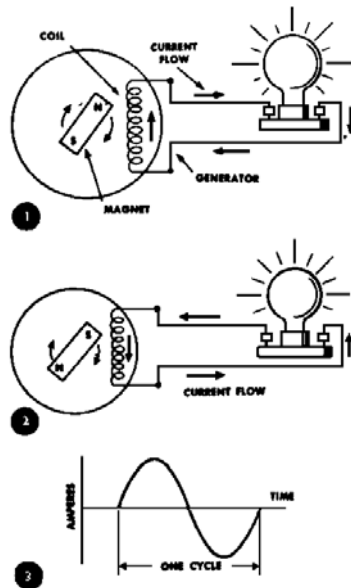


Figure 2-2. Alternating current.

(2) As the south pole (S) passes the coil, a voltage is generated in the opposite direction and current flows in the opposite direction (fig 2-2).

(3) One complete revolution of the magnet constitutes a cycle (fig 2-2).

c. Frequency. Frequency is the number of times an alternating current changes direction in a given period of time. Two changes of direction are a cycle. Normal alternating current in the United States has a frequency of 120 changes per second and is called 60-cycle current. Most European countries use 50-cycle current.

d. Single-phase current. Phase is the number of alternating currents flowing through the circuit. Alternating current described thus far is single-phase current. Since the voltage drops to zero twice in each cycle, the power furnished is uneven and is not suited for operation of some motors. Sixty-cycle, single-phase current gives the motor a push 120 times a second.

e. Three-phase current. Three-phase current is used to power heavy motors and equipment. A three-phase-

current generator consists essentially of a magnet and three coils of wire (fig 2-3). As the north pole (N) of the magnet passes coil 1, a voltage is induced and current flows as indicated by arrows. The south pole (S) induces the voltage and current flow as shown in coil 3. Since neither pole is close to coil 2 at this instant, no current flows. The fluctuating currents in the coils are shown in figure 2-3. Three-phase current pushes the motor 360 times per second and never allows the power to drop to zero. This makes the motor run smoother, the same as an eight-cylinder gasoline engine runs smoother than a one-cylinder gasoline engine.

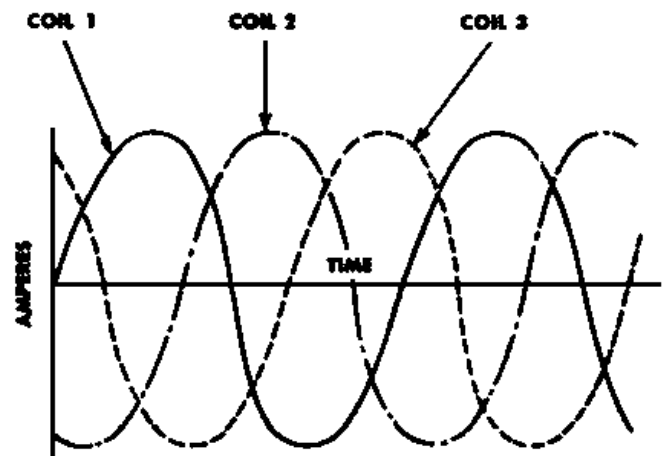
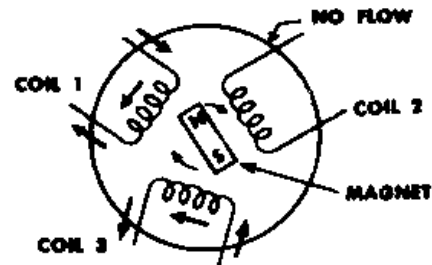


Figure 2-3. Three-phase current.

2-6. ELECTRIC POWER SYSTEMS

a. Two-wire systems. Two-wire systems are always single-phase. One of the wires

may be grounded by connecting it to a water pipe or an iron rod or pipe driven into the ground (fig 2-4). To identify the grounded neutral wire, measure the voltage between each wire and a grounded metal object. If there is no voltage between one wire and ground, that wire is the grounded neutral. The other wire is the hot wire. Switches are connected to interrupt the current flowing in the hot wire.

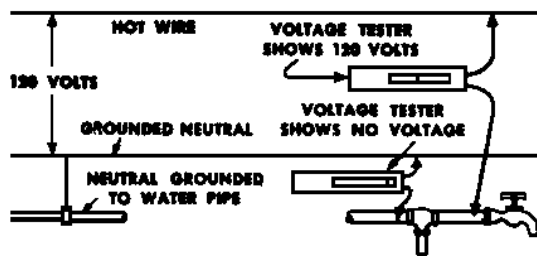


Figure 2-4. Two-wire system.

b. **Three-wire systems.** Three-wire systems may be either single-phase or three-phase.

(1) **Single-phase.** Single-phase, three-wire systems consist of a neutral and two hot wires. The voltage between the two hot wires is twice the voltage between the neutral and either of the hot wires (fig 2-5). A grounded neutral is identified as in the two-wire system. If the neutral is not grounded, it is found by measuring the voltage between each wire and the other two wires. All voltages measured from the neutral wire should be equal.

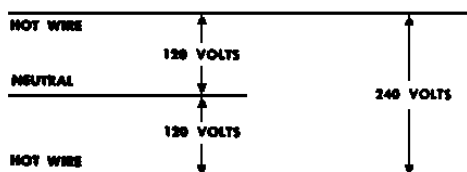


Figure 2-5. Single-phase, three-wire system.

(2) **Three-phase.** Three-phase, three-wire systems consist of three hot wires. The voltages between all wires are equal (fig 2-6).

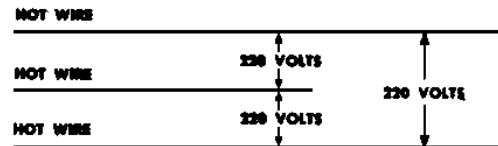


Figure 2-6. Three-phase, three-wire system.

c. **Four-wire systems.** Four-wire systems are usually three-phase. They consist of a neutral and three hot wires (fig 2-7). A grounded neutral is identified as in the two-wire system. If the neutral is not grounded, it is found by measuring the voltage between each wire and the other three wires. All voltages measured from the neutral are equal. Voltage between hot wires is 1.73 times the voltage between neutral and each hot wire.

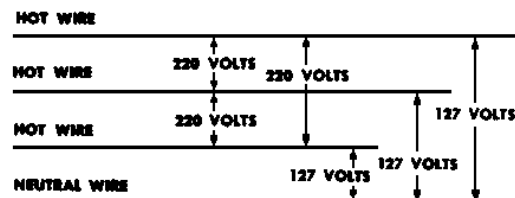


Figure 2-7. Four-wire system.

d. **Balancing loads.** Loads are balanced to provide better voltage for equipment. Figure 2-8 represents a balanced load with 300 watts on each circuit.

(1) In systems having a neutral, the loads are balanced when the total watts of electrical load connected between the neutral and each of the hot wires are equal.

(2) In systems without a neutral, the loads are balanced when the total watts of electrical load connected between each pair of wires are equal (fig 2-9).

(3) It is highly improbable that the loads at an installation can be balanced on the phases exactly. However, the maximum unbalance for circuits should not exceed 10 percent. That means that the load on the heaviest loaded phase is no more than 10 percent greater than the load on the least loaded phase. Preferably, the unbalance should be kept within 1 percent.

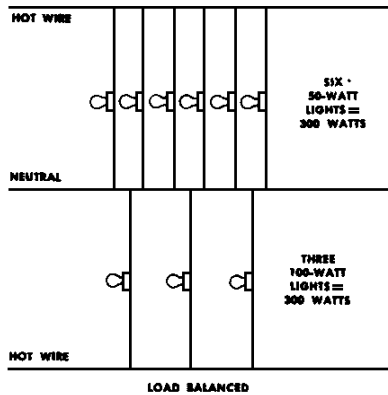


Figure 2-8. Balanced load with two hot wires and one neutral.

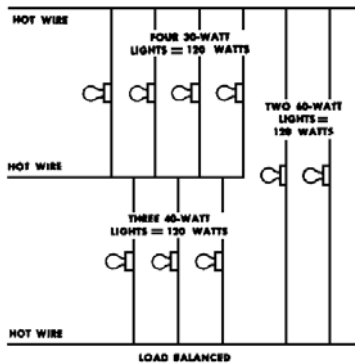


Figure 2-9. Balanced load with three hot wires.

e. System notation. Systems are identified by the number of phases and wires and the voltage between wires. For example, figure 2-5 shows a single-phase, three-wire system; the source of power is a generator. The voltage is 120 volts from hot wire to neutral and 240 volts between hot wires. This notation is abbreviated 10 3w 120/240v. The three-phase four-wire system of figure 2-7 is abbreviated 30 4w 120-208v. When

transformers are used as the means of voltage reduction, the three-phase four-wire voltage will be 120/208 or 115/199.

2-7. SERIES CIRCUITS

Symbols used in circuit diagramming are shown in figure 2-10.

a. Series wiring. Fixtures connected in a circuit by a single wire are wired in series. Series wiring is not practical for the following reasons:

(1) When one of the fixtures burns out or is removed from the line, the circuit is broken, current will not flow, and the remaining fixtures cannot be used.

(2) Fixtures requiring different amperages cannot be used efficiently in the same circuit. The amount of electricity that can pass through the fixtures is limited to the amperage of the smallest fixture. Low-amperage lamps limit electricity flowing through the wires and high-amperage lamps will not produce light.

b. Unit calculations.

(1) **Ohms.** In a series circuit, the total resistance (ohms) is the sum of the resistances in each part of the circuit. Figure 2-11 shows a series circuit with a battery producing 12 volts and three lamps connected in

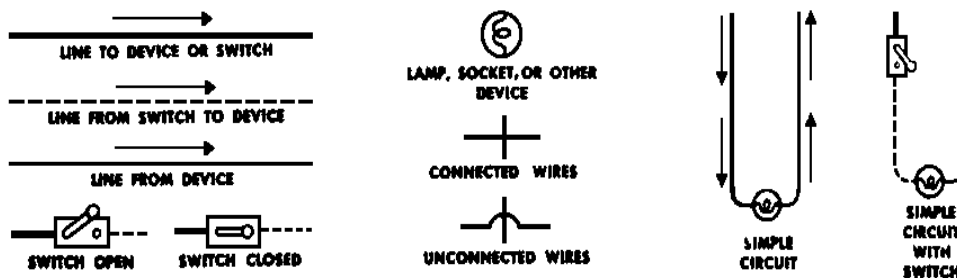


Figure 2-10. Symbols used in circuit diagramming.

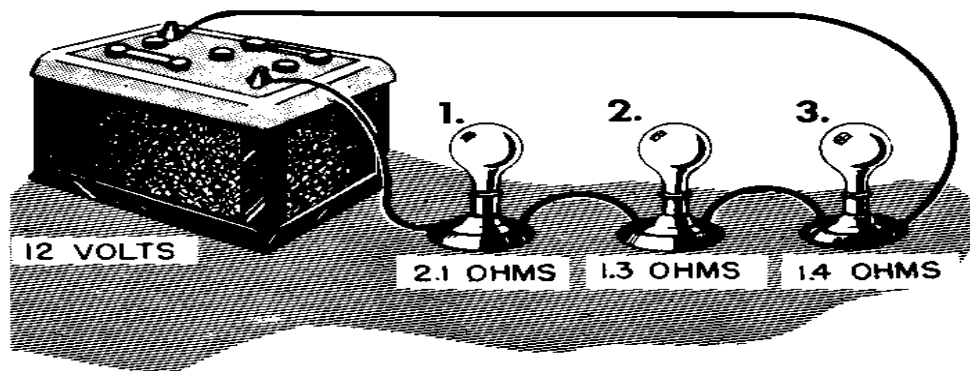


Figure 2-11. A series circuit.

series. Assume the wires have negligible resistance. The lamps have resistances of 2.1 ohms, 1.3 ohms, and 1.4 ohms. The total resistance in this circuit is:

$R = R_1 + R_2 + R_3$ or $2.1 + 1.3 + 1.4$, or 4.8 ohms.

(2) **Amperes.** In a series circuit, the amperage of the current in any one part of the circuit is equal to the amperage of the current in any other part, and is equal to the amperage of the total current. This is expressed by the equation:

I (amperes) total = I_1 , = I_2 , = I_3 .
According to Ohm's law, the current in the circuit of figure 2-11 is:

E (volts) total	12
I total = $\frac{\text{-----}}{\text{R (ohms) total}}$	$= \frac{\text{---}}{\text{4.8}}$
	2.5 amperes

This means that 2.5 amperes flow in each part of the circuit.

(3) **Volts.** Each part of the element of the circuit in figure 2-11 consists of a known resistance with 2.5 amperes flowing through it. If Ohm's law is applied to each part of the circuit, that is, if the current in each part is multiplied by the resistance of that part, a voltage E will be obtained. These separate voltages are known as voltage drops. They are found by multiplying the

resistance of that part by the amperage.

The voltage drop in the first part is:

$$E_1 = I_1 \times R_1 = 2.5 \times 2.1 = 5.25 \text{ volts.}$$

The voltage drop in the second part is:

$$E_2 = I_2 \times R_2 = 2.5 \times 1.3 = 3.25 \text{ volts.}$$

The voltage drop in the third part is:

$$E_3 = I_3 \times R_3 = 2.5 \times 1.4 = 3.5 \text{ volts.}$$

In a series circuit, the total applied voltage is equal to the sum of the individual voltage drops. This can be expressed by the equation:

$$E \text{ total} = E_1 + E_2 + E_3.$$

In the problem,

$$E \text{ total} = 5.25 + 3.25 + 3.5 = 12 \text{ volts, the total applied voltage.}$$

The relation of Ohm's law to series circuits may be worded in another way: The current in amperes in such an electric circuit can be found by dividing voltage by total resistance in ohms. This statement, however, may be hard to remember. The diagram, figure 2-12, will help to fix the law in your mind. Study the diagram. E stands for pressure in volts; I stands for current in amperes; R stands for resistance in ohms.

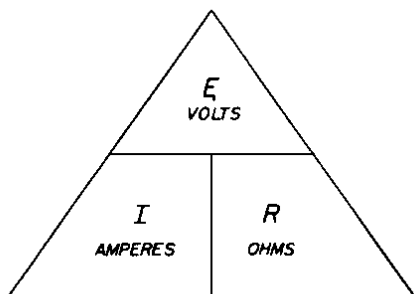


Figure 2-12. Application of Ohm's law.

Work a simple problem with the triangle. Suppose that you wish to find how many amperes a pressure of 1 volt will force through a resistance of 1 ohm. Cover I in the triangle with a finger. Notice the positions of E and R. E is located over R and the two letters are separated by a horizontal line. The line indicates division.

You now have:

$$I \text{ (amperes)} = \frac{E \text{ (volts)}}{R \text{ (ohms)}}$$

$$\text{or } I = \frac{E}{R}$$

By replacing the letters E and R with numbers you get:

$$I = \frac{1}{1} = 1 \text{ ampere}$$

An electric appliance has a resistance (a nameplate reading) of 20 ohms. How many amperes will the appliance take when connected to a 120-volt line?

$$I = \frac{E}{R} = \frac{120}{20} = 6 \text{ amperes}$$

Ohms can be found in the same way that you found amperes. Suppose that you want to find the resistance that will allow a current of 2 amperes to flow under a pressure of 10 volts. Place a finger over R in the triangle. You get:

$$R = \frac{E}{I}$$

Replacing the letters E and I with numbers, you have:

$$R = \frac{10}{2} = 5 \text{ ohms}$$

A heater element of an electric range takes 10 amperes at 115 volts. Find the resistance in ohms of the element. Place a finger over the R.

$$R = \frac{E}{I} = \frac{115}{10} = 11.5 \text{ ohms}$$

You can find the volts required to force amperes of current through ohms of resistance by placing a finger over E in the triangle. Notice the positions of I and R. These letters are located side by side. This indicates multiplication.

Suppose that you want to find how many volts are needed to force 1 ampere through a resistance of 10 ohms. Place a finger over E. You get:

$$E = I \times R$$

Then, replacing letters with numbers you have:

$$E = I \times R = 1 \times 10 = 10 \text{ volts}$$

A current of 25 amperes must be sent through an electropolating tank that has a resistance of 1/5 ohm. How many volts must be used? Place a finger over E.

$$E = 25 \times \frac{1}{5} = 5 \text{ volts}$$

2-8. PARALLEL CIRCUITS

In a parallel circuit, half the terminals of the elements are connected together to form one "side" of the system. The remaining terminals are also connected to form the other sides of the system. Consequently, as figure 2-13 shows, there are as many paths for the current as there are elements in the circuit.

a. Volts. In a parallel circuit, the voltage across each element part of the circuit is the same. Assuming that the wires of the circuit in figure 2-13 have no resistance, the 12 volts

of the battery are applied to each lamp. This can be expressed by the equation:

$$E_{\text{total}} = E_1 = E_2 = E_3 = 12 \text{ volts.}$$

b. Amperes. In the circuit in figure 2-13, the resistance of each part is shown. The voltage across each part is 12 volts. By applying Ohm's law to each part, the current-flow in each lamp can be determined.

The current in the first part is:

$$I_1 = \frac{E_1}{R_1} = \frac{12}{12} = 1 \text{ ampere}$$

The current in the second part is:

$$I_2 = \frac{E_2}{R_2} = \frac{12}{4} = 3 \text{ amperes}$$

The current in the third part is:

$$I_3 = \frac{E_3}{R_3} = \frac{12}{6} = 2 \text{ amperes}$$

In a parallel circuit, the total current or amperes is equal to the sum of the currents flowing in each part of the circuit. This can be expressed by the equation:

$$I_{\text{total}} = I_1 + I_2 + I_3$$

Thus the total current in this circuit is:

$$1 + 3 + 2 = 6 \text{ amperes}$$

This current will not be interrupted by the breakage of one of the lamps. Fixtures wired in parallel are independent of each other. If one fixture breaks, the others continue to function. Lamps requiring different amperages can be put into the circuit and each one shines with its normal brilliance. This system is used in nearly all wiring.

c. Ohms. Unlike a series circuit, the total resistance in a parallel circuit is not equal to the sum of the resistance in each

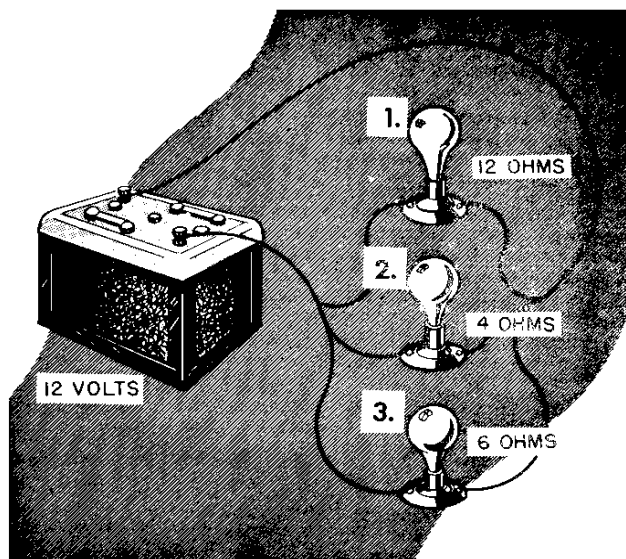


Figure 2-13. Parallel circuit.

part. Total resistance is found by using the following equation:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

For example, take the parallel circuit in figure 2-13. Replacing letters with numbers, you have:

$$\frac{1}{R} = \frac{1}{12} + \frac{1}{4} + \frac{1}{6} = \frac{1}{12} + \frac{3}{12} + \frac{2}{12}$$

$$\frac{1}{R} = \frac{6}{12} = \frac{1}{2}$$

By cross-multiplying $\frac{1}{R}$ total = $\frac{1}{2}$, you get 2 ohms.

This can be checked by Ohm's law.

$$R \text{ (total)} = \frac{E \text{ (total)}}{I \text{ (total)}}$$

$$R = \frac{12}{6} = 2 \text{ ohms}$$

$$\text{For two } R \text{ in parallel, } R = \frac{R_1 + R_2}{2}$$

Losses of efficiency in an electric motor result from several causes including friction of the moving parts. In the process of producing power, the output of any electric motor is always less than 100 percent of the input. Input is expressed in watts; output usually in horsepower. One horsepower equals 746 watts. A motor with an output of 3 horse-power or 2,238 watts, with an efficiency of 85 percent, for example, will require an input of 2,632 watts:

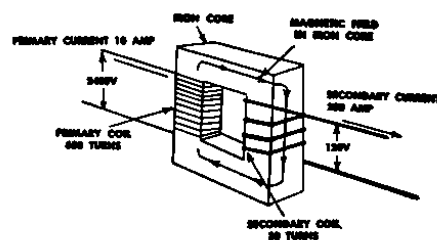
$$\text{Input} = \frac{\text{Output}}{\text{Efficiency}} = \frac{2,238}{.85} = 2,632 \text{ watts}$$

2-9. TRANSFORMERS

A transformer receives electrical energy from one circuit and transfers it to another circuit by magnetic action. The winding by which energy leaves for the load is termed the

secondary. Transformers are generally used to step up or to step down voltages. Therefore, one winding normally is designed for a higher voltage than the other. Either the high- or low-voltage winding may be termed the primary, according to how the transformer is being used.

a. Elementary transformer. An elementary transformer (fig 2-14) consists of a primary and a secondary coil wound on an iron core. Alternating current in the primary coil produces an alternating magnetic field in the iron core. A voltage is induced in the secondary coil by the alternating field.



$$\text{RATIO} = \frac{\text{TURNS IN PRIMARY}}{\text{TURNS IN SECONDARY}} = \frac{500}{10} = 50$$

Figure 2-14. Elementary transformer.

b. Turn ratio. Transformer coils are designed to get the required number of turns into a minimum of space. At the same time the cross section of the conductor must be large enough to carry the current without overheating, and room enough must be provided for insulation and for cooling ducts. The turn ratio of the transformer is--

Number of turns in primary

Number of turns in secondary
This ratio determines the relation between primary and secondary currents and voltages.

$$\text{Primary current} \times \text{turn ratio} = \text{secondary current.}$$

$$\frac{\text{Primary voltage}}{\text{Turn ratio}} = \text{secondary voltage.}$$

That is, if the secondary has twice as many turns as the primary, the voltage in the sec-

ondary will be twice that of the primary, but the amperage will be only half as great. If the secondary has 10 times as many as the primary, the voltage in the secondary will be 10 times that of the primary, but the amperage will be only 1/10 as great.

c. Coil position. In practical transformers, the high-voltage coil surrounds the low-voltage coil, instead of having each coil on a separate leg of the core, as shown in figure 2-14.

d. Coil connection. Many transformers have two identical coils on the primary and two on the secondary. Connecting the two primary coils in series permits operation of twice the primary voltage of the two coils connected in parallel. Series connection of the secondary coils provides a secondary voltage which is twice that of the coils connected in parallel.

e. Taps. Many transformers have taps on the high-voltage winding in order that correct voltage may be maintained on the low-voltage winding when the high-voltage varies by changing the tap connections. Figure 2-15 shows a 2,400/120-volt transformer with two taps on the primary winding. In the transformer, one tap, the 95-percent tap, gives a 19:1 turn ratio; the other, the 90-percent tap, gives a ratio of 18:1. If the primary voltage is 5 percent below 2,400 volts, the transformer is connected to the 95-percent tap, keeping the secondary voltage at 120 volts. To change the tap connection, the transformer is disconnected, the cover removed, the tap-changer operating handle turned to the desired tap. It is not necessary to lower the oil level. In other types of transformers, the taps are brought to a suitable terminal board of porcelain or treated maple fitted

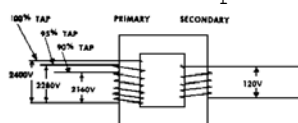


Figure 2-15. Transformer with taps on primary winding.

with porcelain bushings. Links or similar devices are provided for tap changing.

2-10. DISTRIBUTION TRANSFORMERS

Utilization voltage for most military electrical equipment is 120 or 240 volts. A voltage of 208 volts is also commonly used as three-phase voltage. However, such low voltages are not practical for transmitting appreciable quantities of electrical energy farther than 1,000 to 1,500 ft; therefore, higher distribution voltages are required. Distribution transformers must be used to reduce high distribution voltage to usable value.

a. In the distribution transformer, both the primary and secondary have 2 coils. A secondary coil is wound on each leg of the laminated iron core and a primary coil is wound over each secondary coil. The secondary leads pass through the steel tank and are insulated from it by porcelain bushings. The primary leads are connected to studs on a terminal block. Copper straps on the primary terminal block permit connecting the 2 primary coils in series or parallel. From the terminal block, two primary leads pass through high-voltage porcelain bushings to the outside of the tank. A line inside the tank marks the level to which the tank is filled with transformer oil to aid in cooling and insulating the coils. Transformer oil which has high dielectric strength must be used; ordinary lubricating oil cannot be substituted.

b. A cover with a sealing gasket clamps over the top of the tank, making it oiltight and watertight. Mounting brackets on the outside of the tank secure the transformer to the pole. A sling can be looped under the lifting lugs to raise the transformer into position. The nameplate on the outside of the tank gives the manufacturer's name and operating data, including kilovolt-ampere (kva) rating, primary and secondary voltage, and frequency of the alternating-current circuit to which it is to be connected.

2-11. TRANSFORMERS AVAILABLE IN OVERSEA DEPOTS

a. Plans for an oversea electrical-distribution-system layout should include only the

distribution transformers listed in table 2-1 unless it is known that other transformers are available. This table includes all distribution transformers shipped to overseas depots. Standard utilization voltage is 120 or 240 volts and standard primary voltages for distribution are 2,400, 4,800, 3,300 and 6,600 volts.

b. In some foreign countries, standard utilization voltage is 230 volts. Transformers are available (table 2-1) to reduce this voltage to 120 volts for lighting load.

2-12. TRANSFORMER POLARITY

Transformer polarity refers to the order in which primary and secondary leads are brought out of the tank. Transformer polarity is either additive or subtractive and is stamped on the nameplate. Polarity is important only when transformers of different polarities are connected in parallel or are used to supply three-phase service. When transformers are the same polarity, it is immaterial whether they are additive or subtractive.

a. Standard practice. In the United States, additive polarity is standard for all single-phase distribution transformers 200 kva and below which have high-voltage ratings of 7,500 volts and below. Other single-phase distribution transformers are subtractive polarity.

b. Lead markings. Standard rules specify that high-voltage leads be marked H1, H2, and so on, and that low-voltage leads be marked X1, X2, and so on. Lead marking is shown on the transformer nameplate, not on the leads themselves. The H1 lead is brought out on the left side of the transformer case when facing the low-voltage side. If H1 and X1 are on the same side of the transformer tank, polarity is subtractive. If H1 and X1 are diagonally opposite, polarity is additive.

c. Test for polarity. If the nameplate is missing, polarity can be found as follows:

(1) Connect one high-voltage lead to the adjacent low-voltage lead.

(2) Energize high-voltage lead with any reduced alternating-current voltage.

(3) Measure voltage between unconnected high- and low-voltage leads. If it is higher than voltage applied across high-voltage leads, polarity is additive. If lower, polarity is subtractive.

2-13. SINGLE-PHASE AND THREE-PHASE TRANSFORMER CONNECTIONS

a. Paralleling transformers.

(1) When the load on a single-phase transformer is so great that it overloads the transformer, one of the following steps must be taken:

(a) Install a larger transformer.

(b) Transfer part of the load to another transformer.

(c) Connect two transformers in parallel.

(2) Two transformers operating in parallel should have the same ratio and approximately the same impedance. Impedance, or the opposition to flow of alternating current, is stamped on the transformer nameplate. If the transformers are not alike, the load does not divide equally between them, and one is overloaded before the other is fully loaded. In extreme cases, a current circulates between them and causes overheating; as a result, the two transformers carry less load than one of the transformers alone.

Caution: Before making final connections to the low-voltage side of the transformer, place 5-amp fuses in low-voltage leads of one transformer as a final check on accuracy of connections. If fuses blow, check connections.

b. Basic three-phase connections.

The two transformer connections commonly used for three-phase service are the Delta connection (fig 2-16 and the Y or star connection (fig 2-17).

(1) Delta connection. The Delta connection, used for three-phase three-wire circuits, is made by connecting adjacent terminals of transformers. The right lead of one winding is connected to the left lead of the next winding. Coil voltage equals phase-to-phase voltage of the line. Coil current equals

Table 2-1. Weights and Cubages of Transformers Available In Theater of Operations of Operations Class IV Supply

Frequency	50 or 60 cycles												25 cycles					
Primary voltage	230		2,400/4,800		3,300/6,600		11,000/22,000		15,000		33,000		2,400		3,300/6,600		30,000	
Secondary voltage	115/120/125		120/240		120/240		3,300		3,300		3,300		120/240		120/240		3,300	
	lb.	cu. ft.	lb.	cu. ft.	lb.	cu. ft.	lb.	cu. ft.	lb.	cu. ft.	lb.	cu. ft.	lb.	cu. ft.	lb.	cu. ft.	lb.	cu. ft.
Single phase																		
½ kva	41	.5																
1 kva	50	.6																
3 kva	185	2.0																
5 kva	210	2.2	343	12.8	350	10.8							485	12.4	533	20.9		
10 kva	377	3.7	628	18.9	672	17.8							699	19.2	772	24.3		
25 kva			850	20.4	860	20.8												
37½ kva			912	25.7	1,112	27.3												
100 kva			2,742	78.1														
Three phase																		
150 kva							6,015	136.4	5,900	106.0	7,460	191.6					10,085	237.0
300 kva							7,985	174.4	7,985	174.4	9,508	221.7					13,841	295.3

Notes. Values shown are for transformers packed for export.
Fifty-cycle transformers may be used on sixty-cycle circuits.

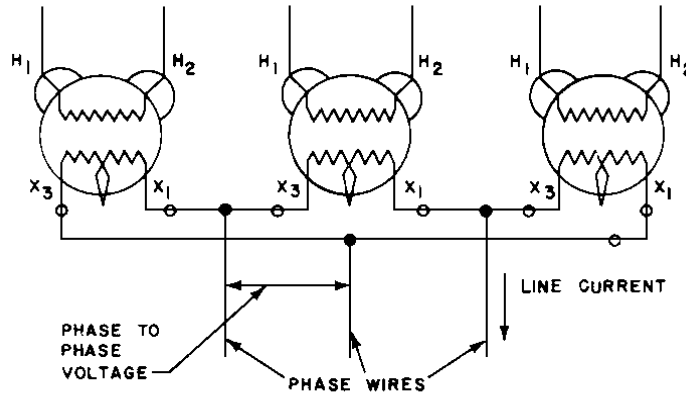


Figure 2-16. Delta connection.

line current in each phase wire divided by 1.73 (fig 2-16).

(2) **Y-connection.** The Y-connection used for three-phase four-wire circuits is made by connecting the three right (or left) leads to a common neutral (fig 2-17). The three left (or right) leads are connected to the phase wires of the lines. Coil current equals line current in each phase wire. Coil voltage equals phase-to-neutral voltage. Thus, when three 2,400-volt transformers are Y-connected to a circuit which measures 2,400 volts from phase-to-neutral or 4,160 volts from phase-to-phase, coil voltage is 2,400 volts.

c. Connecting transformer banks.

Three single-phase transformers connected to a three-phase circuit are called a bank of transformers. Connections are made with a combination of Delta and Y-connections.

(1) **Delta-Delta connection.** A bank of transformers is Delta-Delta connected when the primary windings and the secondary windings are both connected in Delta.

(2) Open-Delta connection.

(a) When one of the three transformers in a Delta-Delta bank fails, it can be disconnected entirely from the bank, converting it to an open-Delta connection for emergency operations. No other change in con-

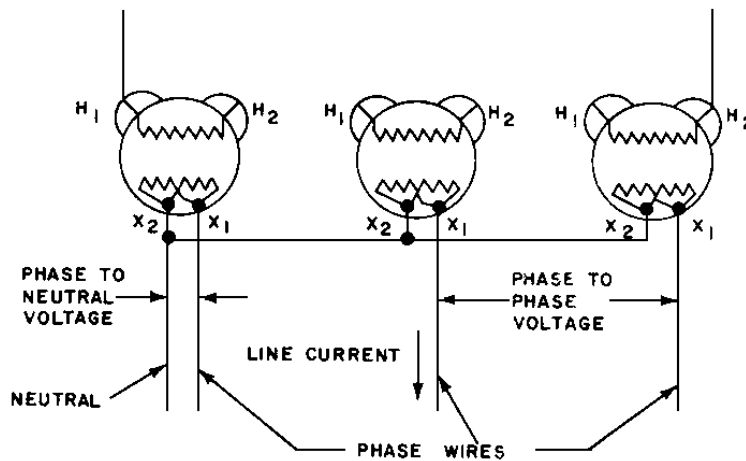
nection is necessary. The open-Delta connection delivers three-phase power using only two single-phase transformers. Removing one of the three transformers reduces capacity of the bank to 58 percent of original capacity instead of 66 2/3 percent, as might be expected.

(b) The open-Delta connection is also used where there is a large single-phase load and only a small three-phase load. In this case, the transformer supplying the single-phase load is larger than the other transformer and is grounded at its midpoint. Only one such point may be grounded on the transformer bank. The midpoints of both transformers must not be grounded.

(3) Y-Delta connection.

(a) A bank of transformers is Y-Delta connected when the three primary windings are Y-connected and the three secondary windings are Delta-connected. When a primary is connected in Delta and the secondary in Y the bank is Delta-Y connected.

(b) The Y-Delta connection continues to operate when one of the transformers is removed, converting it to open Y-Delta. The neutral point of the two remaining transformers must be connected to the primary neutral. This connection creates an unbalanced condition and causes excessive current to flow in the neutral. It should be avoided except in emergencies.



$$\text{PHASE TO PHASE VOLTAGE} = \sqrt{3} \text{ PHASE TO NEUTRAL VOLTAGE}$$

Figure 2-17. Y or star connection.

(4) **Y-Y Connection.** With the Y-Y connection both 120-volt single-phase lighting and 208-volt three-phase power can be obtained from the four-wire secondary.

d. Three-phase transformers.

(1) Three separate transformers built together and placed in the same tank or wound on the same core are three-phase transformers. Connections between coils are made within the tank and only leads which connect to the primary and secondary are brought out through bushings. Three-phase transformers are light, save space, and are more easily connected than three single-phase transformers of equal capacity.

(2) One disadvantage of the three-phase transformer is that if one winding becomes unserviceable, it is probable that the entire bank also would be unserviceable. When this happens, the whole unit must be replaced or service disconnected while repairs are made. Single-phase transformers connected in a bank may use emergency open-Wye or open-Delta connections while the damaged unit is replaced or repaired.

e. Paralleling three-phase transformers. To parallel three-phase transformers, connect corresponding leads to the same conductor.

f. Selection of transformer connection. Selection of a transformer connection depends on voltage of the primary circuit, voltage rating of the available transformers, ratio of the transformers, and the secondary voltage required. If both light and three-phase power are to be supplied from the transformers, the secondary should be connected in Y to form a three-phase four-wire system. In this case, the lighting load is connected between the neutral and the phase wires, and the power load is connected between phase wires only. Table 2-2 gives the ratio between primary and secondary voltage for transformer connections discussed above.

g. Reversed connections. A three-phase motor can be made to rotate in either direction by reversing two of the phase leads to the motor. Thus, when a bank of transformers is replaced, all motors may run backwards. If this occurs, reverse two of the phase wires on either the primary or the secondary of the transformers to correct the direction of rotation.

TABLE 2-2. Ratio Between Primary and Secondary Voltages For Three-Phase Transformer Connections

Transformer primary	Connections secondary	Primary line voltage (phase to phase)	Secondary line voltage (phase to phase)
Delta	Delta	E_p	$E_s \times R$
Wye	Delta	E_p	$\frac{E_s \times R}{1.73}$
Delta	Wye	E_p	$1.73 E_s \times R$
Wye	Wye	E_p	$E_s \times R$

Note. R = turn ratio of transformer = $\frac{\text{rated voltage, phase winding, secondary}}{\text{rated voltage, phase winding, primary}}$

2-14. PROTECTION

Since transformers have no moving parts, the chief causes of damage are electrical disturbances such as short circuits or lightning. These disturbances damage insulation surrounding the coils or porcelain bushings through which the coil leads pass. A short circuit is an abnormal connection, either deliberate or accidental, which permits excessive current flow. This heats the transformer coils to such a high temperature that the insulation is cooked and becomes brittle or even carbonized. When this occurs, the insulation is no longer effective.

a. Fuses

(1) A fuse is an intentionally weakened spot in an electrical circuit which protects equipment from damage by short circuits. The fuse melts or "blows" when the current becomes too large, opening the circuit and preventing current flow.

(2) Every transformer must be protected by an individual primary cutout (fuse) device located in the primary connection, between the transformer primary and the primary line.

(3) The size and voltage of the transformer being protected determine the fuse size. Fuse protection against small overloads on the transformer is not good practice since the fuse would blow frequently, causing needless interruption to service. Table 2-3 gives fuse sizes for use with a given transformer.

(4) All transformers should be protected fuses in the primary connection.

TABLE 2-3. Fuse Sizes (in amperes) for Use With Distribution Transformers

Transformer size (kva)	Coil voltage				
	2,400	3,300	4,800	6,600	11,000
5	5	5	5	5	5
10	10	5	5	5	5
25	25	15	10	10	5
37½	25	15	15	10	5

b. Lightning arresters.

(1) One of the chief sources of trouble on overhead distribution circuits is lightning, which results in damage to wires, insulators, poles, and other equipment, particularly transformer windings. There are two ways lightning may affect the transmission or distribution line, either by striking the line directly or by induced effect. Unless these voltage surges are drained from the lines, they may enter the transformer windings, puncturing the weakest points of the insulation in trying to reach the ground. The best protection against damage by voltage surges is to install a lightning arrester as close as possible to the apparatus it is to protect. In protecting transformers, the high-voltage lead of the arrester is connected on the line side of the cutout; the lower lead is connected to a ground rod. This allows the energy of the surge to escape to the ground without allowing normal energy on the line to follow and sustain an arc, thereby forming a ground on the line. If not properly grounded, the lightning arrester will not function. Careful attention should be given so that a good low-resistance ground is secured. The path to the ground should be as short and straight as possible.

(2) In a typical lightning arrester for distribution voltages, the upper lead is connected to the primary wire as close to the transformer as possible. The lower lead is connected to a ground rod, such as a piece of iron pipe, driven 7 or 8 feet in the ground.

c. Built-in lightning arresters and circuit breakers. Some transformers are protected

from excessive voltages and overloads by lightning arresters and circuit breakers which are an integral part of the transformer. A heavy overload on the secondary opens a breaker inside the tank, disconnecting the transformer from the load. Overloads not large enough to damage the transformer immediately turn on an indicating light on the side of the tank. The glowing indicating light shows that the load is too large and the transformer must be replaced with a larger size or part of the load transferred to another transformer.

2-15. MAINTENANCE

Transformers require little maintenance because they have no moving parts. A visual inspection is usually enough to show whether work is needed.

a. Rust. Check for rust which might lead to complete perforation of the case. Remove rust by scraping, and apply paint.

b. Leaks. Dark spots on the case indicate an oil leak. To locate the leak and repair it--

(1) De-energize transformer.

(2) Wash surface with engineer-issue solvent.

(3) After it dries, dust surface with chalk, cement dust, or whitewash. Escaping liquid will show as a dark spot.

(4) Remove tank cover and drain oil out of tank.

(5) Weld or solder leak.

c. Oil level. Before installation, remove the transformer cover and check oil level in the transformer. If the oil does not come up to the mark inside the case, add transformer oil. Unless there is evidence of a leak, oil level in distribution transformers need not be checked after installation. Transformer oil must be free of moisture, even in small amounts. Take every precaution to protect oil in storage from moisture contamination. Some present-day transformers use special coolants. Such products should not be put into transformers designed for oil nor should oil be put into transformers designed for other coolants.

Follow nameplate recommendations when adding coolant.

d. Safety precautions.

(1) Low voltage, 300 volts.

Personnel may work on energized conductors and equipment operating at 300 volts or less if all adjacent energized or grounded conductors and equipment are covered with insulating material or approved rubber protective equipment. The following safety precautions apply to personnel working on energized conductors and equipment operating at 300 volts or less.

(a) Tape or cover all bare or exposed places on one conductor before another conductor is exposed.

(b) When work is done on building wiring, motors, belting, shafting, blowers, or other machinery (including shop machine tools), open switches and remove fuses. Attach hold cards to the switches.

(c) When handling portable electric tools or light cords, do not touch steam or water pipes.

(d) Never leave joints or loose ends of wire untaped unless otherwise protected.

(e) When working in a building in which a fire has occurred, never turn on the current until the wiring and other electrical equipment have been inspected.

(2) Intermediate voltage, 300 to 5,000 volts. Overhead lines operating between 300 and 5,000 volts must be worked on with rubber gloves. Other lines and equipment carrying 300 to 5,000 volts must be de-energized and grounded before any work is started.

2-16. GENERATORS

a. Types of generators. The practical source of electric power is the generator, which converts mechanical energy into electrical energy. All military generators are driven by a prime mover, which may be a gasoline or diesel engine. Normally, gasoline engines drive military generators under 10kw capacity; diesel engines drive the larger ones.

b. Generator characteristics. The important characteristics of a generator are its

kilowatt (kw) rating, the voltage and frequency at which it generates, and whether it is a single- or three-phase generator. The kw rating determines the horsepower of the prime mover. Frequency depends on speed of rotation and the number of poles of the generator. Voltage also depends on speed, but is varied within limit by changing the strength of the magnetic field. The generator nameplate gives the characteristics of the machine.

2-17. PRINCIPLES OF OPERATION

a. Elementary generators.

(1) An elementary generator (fig 2-18) consists of an armature coil rotating in a magnetic field produced by two field poles. During rotation, the two sides of the coil cut the lines of force of the magnetic field, generating a voltage in the coil. Slip rings and brushes permit continuous electrical contact between the rotating coil and the external circuit.

(2) A single coil rotating in a magnetic field generates single-phase power. Three separate coils, each displaced one-third of a revolution from the other two and rotating on the same shaft in the same field, generate three-phase power.

b. Practical generators.

(1) In practical generators, the magnetic field is produced by direct current

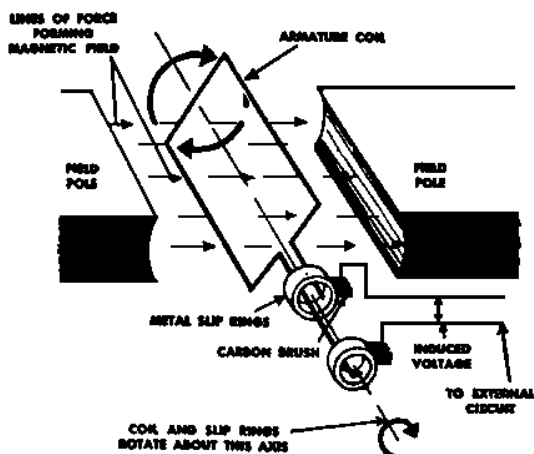


Figure 2-18. Elementary generator.

flowing in the field coils wound around field poles. Increasing the

field current increases the voltage generated. This is the method used to control the voltage of a generator.

(2) In small generators, the field is stationary and the armature rotates. In the larger ones, the field rotates and armature coils are placed in slots in the generator frame.

2-18. DESCRIPTION

a. Single-phase generators.

Single-phase military generators are available in .5 thru 1.5 and 5 kw capacities. They are used for small lighting and motor installations.

b. Three-phase generators. Tables of organization and equipment (TOE) generators are three-phase generators. These generator sets are capable of operating on two frequencies (50 and 60 cycles) and, depending upon the unit, on voltage ranges 120/208, and 240/416. Generators 15 kw and above can be operated as a single unit or in parallel with other generator sets. When in parallel they increase current capacity.

c. Nontactical generators.

Special purpose barges, tankers, and the nuclear powered Sturgis (10,000 kw) are used for base power.

2-19. COMBINATIONS OF GENERATORS AND TRANSFORMERS

a. With high-voltage generators.

High-voltage generators may be connected for three-phase four-wire service or three-phase three-wire service. Ordinarily, rated voltage and normal hookup should be used in practice. However, when the line drop is excessive and voltages are low, the generator may be operated at 2,400 volts instead of its rated 2,300 volts to produce satisfactory voltages; or three-phase transformer banks supplying both lighting and power loads may be connected to the 95-percent tap; or the transformers supplying a single-phase load may be connected to the 100-percent tap. Ground all secondary neutrals. Any of these voltage-raising remedies may be resorted to as a temporary solution. However, such a solution, while correcting low-voltage conditions

during heavy loads, may give such a high voltage during the light loads that the life of the lights and other electrical equipment may be needlessly shortened. It might, therefore, be more economical to have the voltage reasonably low during heavy loads so the voltage under light loads will not be excessive. This procedure should be followed only until a better arrangement can be made, such as installation of an automatic voltage regulator.

(1) Generators connected for 2,300/4,000 volts. Use Y-Y-connected transformers to supply three-phase four-wire secondaries. Connect transformer neutrals together and to ground. Ground generator neutral.

(2) Generators connected for 2,300 volts. Use Delta-Y-connected transformers to supply three-phase four-wire secondaries.

b. With low-voltage generators. To eliminate excessive voltage drop caused by supplying electric energy from low-voltage generators, install transformers near the generator. Connect generator leads to low-voltage windings of transformers, energizing high-voltage windings. Additional low-voltage load may be supplied directly from the generator without going through the transformers.

2-20. ELECTRICAL LAYOUT

a. Electrical diagrams are usually brief. It is impractical as well as unnecessary to show the details of connection for each lamp and switch. For this reason, a set of standard symbols has been adopted to indicate the different outlets and fixtures. The exact locations of the wires and cables are not shown in the electrical plans. All that is shown is the sequence of connections and the switch layout for the operation of the lights or equipment. The exact manner of making the connections and placing the wires is left to the electrician.

b. Electric power from civilian sources is used if available, unless considered inadequate or subject to frequent interruption. In areas where it is not possible to connect to existing power sources, portable military generators are used.

2-21. PHASES OF CONSTRUCTION

a. Collection of data. The first consideration is the collection of data. This includes a reconnaissance to determine the capacity of the source of electric power and the type, size, and intended use of the building. The source must be large enough to supply the entire load.

b. Planning and design. The second stage is planning and design. If plans are available for the electrical layout, you must check them, as well as the specifications and bill of materials, for accuracy. If such plans are not available, you must know the locations of doors, windows, and partitions because these affect the placement of receptacles and switches. In some cases, you will need to know the location of furnishings, such as desks and workbenches, so that lights can be placed to give maximum illumination where needed.

c. Installation. The next objective is the installation of the wires and equipment. Your instructions to the workmen must be clear and complete so they understand what is to be done and how it is to be accomplished. Installation of electric wiring must meet all safety requirements as established by Department of the Army policy. In electric wiring as in all other types of construction, you, as officer in charge, must exercise constant supervision and control. You should maintain proper coordination with plumbers, painters, carpenters, or other labor who may be working on the same building. When this is the case you should maintain continuous supervision to keep all men working without interference.

d. Testing. After the wires and equipment are installed, you should test each circuit to be sure that it is complete and will operate correctly. Only by close inspection can hazards be detected and incorrect installations discovered. Building wiring, if properly installed, requires only a minimum of maintenance. Engineer units are responsible for the maintenance and repair of most electrical installations.

2-22. LOAD ESTIMATION

The entire layout of the distribution system depends on load estimation. Load estimation covers both magnitude and location of the load.

a. Location of load. To estimate the load, first obtain a map of the area to be served with electricity and locate and mark on it the various structures to be connected to the distribution system. Identify each building, such as barracks, recreation hall, warehouse, and shop.

b. Determining connected load. Secondly, determine the connected load for each structure served. Connected load for a given building is the sum of the horsepower of all motors and the wattages of all lights and other electrically operated devices. It is usually expressed in kva. For load estimation, 1,000 watts of lighting load or 1 horse-power of motor or power load equals 1 kva. Table 2-4 gives connected lighting and power loads for typical theater-of-operations structures.

c. Demand load. Connected load must be converted to demand load. The terms load or demand, used alone, mean demand load. Demand is the maximum kva required to serve a given connected load. Demand is less than connected load because all connected equipment seldom is operated simultaneously. The ratio between demand and connected load is the demand factor.

$$\text{Demand} = \text{demand factor} \times \text{connected load.}$$

Typical military demand factors are given in table 2-5. Compute the demand for each structure and record it on the map at the proper location. Record the type of service (three-phase four-wire, single-phase two-wire 3-4W 102W) required for each structure.

2-23. GENERATOR LOCATION AND CAPACITY

Selection of generator locations and capacities follows load estimation.

a. Location. To reduce the size of wire required, locate generators near points of large demand, such as laundries, machine shops, bakeries,

ice plants, and X-ray machines. Select tentative generator locations by studying the map on which demands are plotted. Size of the area served by each low-voltage generator depends on type and loca-

TABLE 2-4. Connected Loads For Military Structures

Type of structure	Connected lighting (kva)	Connected power (estimated kva)	Type of service
Barracks, 50-man, 20' x 100' -	0.13		1ø 2w
Bathhouse, battalion, 20' x 52'.	.23	.95	3ø 4w
Bathhouse, company, 20' x 20'	.10	.80	3ø 4w
Boilerhouse for laundry, 2,500-man capacity, 32' x 32'.	.40	3.9	3ø 4w
Boilerhouse for 500-bed-hospital laundry, 10' x 32'.	.2	3.2	3ø 4w
Generator plant, 20' x 20'---	.24		
Hq, bn or regtl, 20' x 100'---	1.63		1ø 2w
Hq, company, 20' x 40' -----	.26		1ø 2w
Hq, division—three 20' x 100' bldgs connected.	4.74		1ø 3w
Ice plant, 15-ton, 40' x 52'---	.26	57.5	3ø 4w
Laundry, 2,500-man capacity, 48' x 110'.	8.2	27.9	3ø 4w
Laundry for 500-bed hospital, 48' x 64'.	3.8	25.3	3ø
Machine shop, 60' x 140'----	20.0	50.3	3ø 4w
Mess hall, 20' x 100' -----	.90		1ø 2w
Post Exchange, 20' x 100'---	1.48	0.80	1ø 3w
Recreation bldg, 58' x 92'---	18.58		3ø 4w
Recreation hall, 20' x 100'--	1.6		1ø 2w
Shop, 48' x 112' -----	1.20	10.0	3ø 4w
Warehouse, 20' x 100' -----	.13		1ø 2w
Warehouse, refrigerated, 20' x 100'.	.2	22.65	3ø 4w

TABLE 2-5. Demand Factors For Military Installations

Installation	Demand factor
Ice plants, bakeries, laundries -----	1.00
Barracks, quarters, warehouses -----	.90
Theaters -----	.50
All other structures -----	.90

tion of individual demands in that area. As a general rule, small demands such as barracks lighting are served at distances up to 1,500 feet (wire length); moderate demands, up to 1,000 feet. If the tentative generator locations already selected are too far apart, they may be shifted. Additional generators may be necessary should shifting result in moving generators away from the large demands. The final location should be near a road and on firm ground. A concrete foundation should be provided for 30-kw generators and larger, if the generator installation is semi-permanent.

b. Capacity. Generating capacity at each location is proportional to the sum of individual demands in the area served. The sum of individual demands is larger than generating capacity required, since demands do not occur simultaneously. Furthermore, demand so obtained is measured in kva, while generators are related in kw. Table 2-6 gives generator factors used in the following formula for converting the sum of individual demands to generator capacity.

Generator capacity in kw =
generator factor X sum of individual demands in kva.

TABLE 2-6. Generator Factors For Converting Demand Load To Generator Capacity

Type of load	Generator factor
Lighting	1.00
Predominantly lighting with some motors .....	.85
Lighting and motors about equal .....	.90
Predominantly motors with some lighting .....	.85
Motors .....	.80

Note. Generator factor allows for both power factor (pf) and noncoincident demands.

c. Operating in parallel.

(1) Requirements. Two generators are operating in parallel when the leads of both are connected to the same electrical system and each is supplying power. The most common use of parallel operation is two or more generators feeding a large common conductor called a bus. The phase rotation, frequency, and voltage of generators must be the same before they are operated in parallel.

(2) Compensating phase. A current transformer, used to measure current supplied by the phase, sur-

rounds each of the three phase leads of the generator. In addition, one phase has a separate current transformer which is connected to the compensating resistor of the voltage regulator. The phase with two current transformers is the compensating phase. The other two phases are the non-compensating phases. The compensating phase is found by tracing wiring from the generator until the phase surrounded by two current transformers is found. For satisfactory parallel operation, compensating phases of all generators should be connected to the same phase of the bus.

(3) Test for phase rotation.

Phase rotation is the order in which phase leads from a generator are connected to the bus. It is reversed by interchanging any two phase leads. Phase rotation is established by test when the leads from a newly installed generator are wired to the bus; no further check is required.

(b) To check phase rotation in low-voltage generators by means of test lamps, connect the generator neutral to the bus neutral. Connect the two non-compensating phase leads of the generator through test lamps to the two non-compensating phases of the bus. The test lamps for each phase consist of two light bulbs in series. (Combined voltage rating of these lamps must equal or exceed the rated voltage of the alternators, unless transformers are used.) Leave the compensating phase disconnected. Start the new machine and close the main circuit breaker. Adjust the speed of the new machine until the frequency and voltage of both machines are approximately the same. When this is done, the test lamps will flash on and off. If lamps in one phase are dark at the same instant that the lamps in the other phase are bright, phase connections are reversed and must be changed. If lamps in the two phases flash off together, phases are properly connected and phase rotation of the new machine is the same as that of the bus. Remove test lamps and connect all three generator phase leads to corresponding phases of the bus.

(b) To check phase rotation using a three-phase motor, connect the bus, new generator, and three-phase motor to a three-pole double-throw knife switch. Start the new machine and close the main circuit breaker. Adjust the voltage and frequency of the new machine until they are approximately the same as the voltage and frequency of the bus. Throw the knife switch to the left and note the direction in which the motor shaft turns. Throw the knife switch to the right and again note the shaft rotation. If it is now turning in the opposite direction, interchange the two non-compensating phase leads of the new machine at the knife switch. When the motor turns in the same direction whether connected to the bus or new machine, phase rotations of the bus and new machine are the same. Remove the knife switch and connect all three generator phase leads to corresponding phases of the bus.

(4) Synchronizing. Each time a generator is connected to an energized bus by closing main circuit breaker, it must be synchronized with the bus; that is, its frequency and voltage must be made the same as that of the bus. The generator which is to be synchronized is called the incoming machine. There are two methods of synchronizing military generators, depending on whether the control panel has synchronizing lamps.

(a) Machines with synchronizing lamps. Start the machine as described in (3)(a) above, except that main circuit breaker is OFF and synchronizing lamps are ON. Voltage and frequency of the incoming machine and bus should be as nearly equal as possible. Synchronizing lamps will flash on and off at a frequency dependent on the difference between frequencies of the incoming machine and the bus. Adjust frequency of incoming machine until lamps flash on and off slowly. At the instant lamps are dark, close main circuit breaker, paralleling the incoming machine with bus.

(b) Machines without synchronizing lamps. Start the machine as described in (3)(a) above, except that main circuit breaker is OFF. Voltage and

frequency of the incoming machine and bus should be as nearly equal as possible. In rapid succession, place field switch in OFF position, main circuit breaker in ON position & field switch back in ON position. Divide the load equally as possible between the machines by adjusting the engine governors until the ammeters show that equal currents are carried by corresponding phases of each machine.

(5) Adjusting load. Adjust the load of machines operated in parallel by changing the governor setting. Turning the governor-setting knob in the increase-speed direction increases the load carried by the machine. Adjust governors until ammeters show that currents supplied by each machine are roughly proportional to the kilowatt capacity of the generator. If all generators are same size, they should supply approximately equal currents.

d. Number of generators. There are always several possible generator combinations which will supply required capacity. However, some of these selections are inefficient. It is possible to select one large generator to supply total required capacity. However, this selection becomes inefficient at night when the required power is reduced. Since the generator will run at a constant output, much more power will be supplied than is actually required. Another possibility for supplying the needed capacity is to combine generators of different sizes to obtain the required value, e.g. supply a capacity of 25KW with one 10 & one 15KW generator. This combination requires repair parts for each of the generators and often excludes the possibility for interchangeability of repair parts. Thus such selections are inefficient from a supply standpoint. Normally, 2 generators, each to supply 2/3 of the required capacity, or three generators, each at 1/2 of the capacity, are good combinations to use. A standby generator should be provided so that service will not be curtailed if any operating generator fails. Selections such as the ones above will allow the operators to shut one down at night when loads are at a minimum. This will

greatly assist in the performance of maintenance on this equipment.

e. Interconnection. Generator locations in hospital areas are connected so that failure of generators at one location does not interrupt service. The interconnection requires large wires and is not justified for other types of load. In addition to interconnection, hospital should have enough extra generating capacity so the load can be supplied when the largest generator is out of service.

2-24. TRANSFORMER LOCATION AND CAPACITY

Transformers are required wherever utilization voltage differs from distribution voltage.

a. Location. General principles used in selecting generator locations apply to the selection of transformer locations. Load centers, such as machine shops, laundries, and bakeries, normally require three-phase banks of transformers. Lighting and small-motor loads are served by single-phase transformer installations.

b. Capacity. The kva rating of the transformer selected is equal to kva demand of the load served. The kva demand is not multiplied by the generator factor, as in selecting the generator size. A 10-kva transformer connected to No. 6 three-wire single-phase 120/240-volt 103W 120/240 volt secondaries is often used to supply military lighting loads from primary circuits.

2-25. LINE LOCATION

Distribution lines conduct electric power from generators to using equipment. The lines radiate from generator locations, branching and re-branching until they reach all structures within the area to be served. The lines generally are located parallel to building rows, and are supported either by poles, by masts attached to buildings, or by buildings themselves. High-voltage lines are not attached to masts or buildings.

2-26. WIRES AND CABLES

Most current-conducting wires and cables are made of copper. The copper conducting wire is covered with

different materials and varies in size. The size used depends on the current to be carried by the wire, the position and type of installation of the wire, and the importance of the electrical line. The two most common types of wire insulation furnished are cotton braid and rubber. Cotton braid is used for most common knob-and-tube wiring. Rubber insulation is used in wet places such as shower rooms to minimize accidental grounding and danger from shocks.

a. Wire sizes. Common small wire sizes are denoted by number, ranging from No. 40, the smallest, to No. 4/0, the largest (table 2-7). The even-numbered sizes are the only types in common use. Sizes 6 or 8 are commonly used in pole-to-building wiring; size 14 in building wiring; and sizes 16 or 18 in appliance and signal wiring. Sizes 10 to 4/0 are generally used to carry powerline currents. Wires larger than No. 4/0 are usually used in power-station work and are listed and sized by their cross-sectional area in circular mils. A circular mil is the area of a circle one thousandth of an inch in diameter.


b. Stranded wire or cable. In large sizes, a solid wire would be stiff and hard to handle, so a number of smaller wires are twisted together to make a cable of the same cross-sectional area as the single large wire. Number 6 wire and larger is usually stranded.

c. Insulation. Insulation around current-carrying wires makes the wire safe to handle at low voltages. The wire is usually covered by an inner layer of rubber or fabric and a reinforcing layer of cotton braid.

d. Selecting wire sizes. Wire sizes used in standard theater of operations buildings are given in the electrical notes of the drawings in TM 5-302. When installing wire in nonstandard buildings, tables 2-8 through 2-10 can be used in selecting wire sizes. Tables are based on approximately 3 percent voltage drop.

Example: To supply a 220 volt 40 ampere load at a distance of 100 feet (with no more than a 3 percent voltage drop), what is the wire size?

TABLE 2-7. Wire Sizes and Specifications

NUMBER	SIZE		WEIGHT (FEET PER POUND)	CURRENT-CARRYING CAPACITY (AMPERES)			RESISTANCE (OHMS PER 1,000 FEET)
	NATURAL SIZE	DIAMETER (INCHES)		RUBBER- INSULATED WIRE IN CONDUIT OR CABLE	RUBBER- INSULATED WIRE ON INSULATORS	WEATHER- PROOF WIRE ON INSULATORS	
40	TOO SMALL TO SHOW ACCURATELY	.0031	33,410	---	---	---	---
36		.0030	13,210	---	---	---	---
30		.0102	3,287	---	---	---	---
24		.0201	817.4	---	---	---	---
18		.0403	203.4	---	---	---	---
16		.0506	127.9	---	---	---	---
14		.0640	80.44	15	24	30	2.48
12		.0806	50.59	20	31	39	1.56
10		.1018	31.82	25	42	54	0.98
8		.1284	20.01	35	58	71	0.62
6		.184	12.58	50	78	98	0.39
4		.232	7.91	70	105	130	0.24
2		.292	4.97	90	142	176	0.15
1		.332	3.94	100	164	203	0.12
1/0		.373	3.13	125	193	237	0.10
2/0		.419	2.48	150	223	274	0.08
3/0		.470	1.97	175	259	318	0.06
4/0		.528	1.56	225	298	368	0.05
350 MCM		.681	0.925	300	421	508	0.03

SIZES 40 TO 8 ARE SOLID WIRES. SIZES 6 TO 2 ARE 7-STRAND CABLES. SIZES 1 TO 4/0 ARE 19-STRAND CABLES. SIZE 350 MCM IS A 37-STRAND CABLE.
MCM IS THE DESIGNATION OF WIRE SIZE IN THOUSANDS OF CIRCULAR MILS. 350 MCM = 350,000 CIRCULAR MILS.

TABLE 2-8. Wire Sizes For 120-Volt, Single-Phase Circuits

LOAD (AMPS)	MINIMUM WIRE SIZE (AWG)	SERVICE WIRE SIZE (AWG)	WIRE SIZE (AWG)											
			DISTANCE ONE WAY FROM SUPPLY TO LOAD (FT)											
			50	75	100	125	150	175	200	250	300	350	400	500
15	14	10	14	12	10	8	8	6	6	4	4	4	2	2
20	14	10	12	10	8	8	6	6	4	4	2	2	2	2
25	12	8	10	8	8	6	6	4	4	2	2	2	1	1
30	12	8	10	8	6	6	4	4	4	2	2	1	1	0
35	12	6	8	6	6	4	4	4	2	2	1	1	0	0
40	10	6	8	6	6	4	4	2	2	2	1	0	0	2/0
45	10	6	8	6	4	4	2	2	2	1	0	0	2/0	2/0
50	10	6	8	6	4	4	2	2	2	1	0	2/0	2/0	3/0
55	8	4	6	4	4	2	2	2	1	0	2/0	2/0	3/0	4/0
60	8	4	6	4	4	2	2	1	1	0	2/0	3/0	3/0	4/0
65	8	4	6	4	4	2	2	1	0	2/0	2/0	3/0	4/0	4/0
70	8	4	6	4	2	2	1	1	0	2/0	2/0	3/0	4/0	4/0
75	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0	
80	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0	
85	6	4	4	4	2	1	1	0	2/0	3/0	3/0	4/0		
90	6	2	4	2	2	1	0	0	2/0	3/0	4/0	4/0		
95	6	2	4	2	2	1	0	2/0	2/0	3/0	4/0			
100	4	2	4	2	2	1	0	2/0	2/0	3/0	4/0			

TABLE 2-9. Wire Sizes For 220-Volt, Three-Phase Circuits

LOAD (AMPS)	MINI- MUM WIRE SIZE (AWG)	SERV- ICE WIRE SIZE (AWG)	WIRE SIZE (AWG)													
			DISTANCE ONE WAY FROM SUPPLY TO LOAD (FT)													
			100	150	200	250	300	350	400	500	600	700	800	900	1,000	
15	14	12	14	12	10	8	8	8	6	6	6	4	4	4	2	
20	14	10	12	10	8	8	6	6	6	4	4	4	2	2	2	
25	12	8	10	8	8	6	6	6	4	4	2	2	2	2	1	
30	12	8	10	8	6	6	6	4	4	2	2	2	1	1	0	
35	12	8	10	8	6	6	4	4	4	2	2	1	1	0	0	
40	10	6	8	6	6	4	4	4	2	1	1	1	0	0	2/0	
45	10	6	8	6	6	4	4	2	2	2	1	0	0	2/0	2/0	
50	10	6	8	6	4	4	2	2	2	1	0	0	2/0	2/0	3/0	
55	8	6	8	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0	
60	8	6	6	6	4	2	2	2	1	0	0	2/0	3/0	3/0	4/0	
65	8	4	6	4	4	2	2	2	1	0	2/0	3/0	3/0	3/0	4/0	
70	8	4	6	4	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0	
75	6	4	6	4	2	2	2	1	0	2/0	2/0	3/0	4/0	4/0		
80	6	4	6	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0	4/0	
85	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0			
90	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0			
95	6	4	6	4	2	1	1	0	1/0	3/0	3/0	4/0				
100	4	2	4	2	2	1	0	0	2/0	3/0	4/0	4/0				
125	4	2	4	2	1	0	2/0	2/0	3/0	4/0						
150	2	2	2	2	0	2/0	2/0	3/0	4/0							
175	2	1	2	1	0	2/0	3/0	4/0	4/0							
200	1	0	1	0	2/0	3/0	4/0	4/0								
225	0	0	0	0	2/0	3/0	4/0									
250	2/0	2/0	2/0	2/0	3/0	4/0										
275	3/0	3/0	3/0	3/0	3/0	4/0										
300	3/0	3/0	3/0	3/0	4/0											
325	4/0	4/0	4/0	4/0												

TABLE IS BASED UPON APPROXIMATELY 3% VOLTAGE DROP

TABLE IS BASED UPON APPROXIMATELY 3% VOLTAGE DROP

TABLE 2-10. Wire Sizes For 240-Volt, Single-Phase Circuits

LOAD (AMPS)	MINI- MUM WIRE SIZE (AWG)	SERV- ICE WIRE SIZE (AWG)	WIRE SIZE (AWG)													
			DISTANCE ONE WAY FROM SUPPLY TO LOAD (FT)													
			100	150	200	250	300	350	400	500	600	700	800	900	1,000	
15	14	10	14	12	10	9	8	6	6	6	4	4	4	2	2	
20	14	10	12	10	8	8	6	6	6	4	4	2	2	2	2	
25	12	8	10	8	8	6	6	4	4	4	2	2	2	1	1	
30	12	8	10	8	6	6	4	4	4	2	2	1	1	0	0	
35	12	6	8	6	6	4	4	4	2	2	1	1	0	0	2/0	
40	10	6	8	6	6	4	4	2	2	2	1	0	0	2/0	2/0	
45	10	6	8	6	4	4	2	2	2	1	0	0	2/0	2/0	3/0	
50	10	6	8	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0	
55	8	4	6	4	4	2	2	2	1	0	2/0	2/0	3/0	3/0	4/0	
60	8	4	6	4	4	2	2	1	1	0	2/0	3/0	3/0	4/0	4/0	
65	8	4	6	4	4	2	2	1	0	2/0	2/0	3/0	4/0	4/0		
70	8	4	6	4	2	2	1	1	0	0	2/0	3/0	4/0	4/0	4/0	
75	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0			
80	6	4	6	4	2	2	1	0	0	2/0	3/0	4/0	4/0			
85	6	4	4	4	2	1	1	0	2/0	3/0	3/0	4/0				
90	6	2	4	2	2	1	0	0	2/0	3/0	4/0	4/0				
95	6	2	4	2	2	1	0	2/0	2/0	3/0	4/0					
100	4	2	4	2	2	1	0	2/0	2/0	3/0	4/0					
125	4	2	4	2	1	0	2/0	3/0	3/0	4/0						
150	2	1	2	1	0	2/0	3/0	4/0	4/0							
175	2	0	2	0	2/0	3/0	4/0	4/0								
200	1	0	1	0	2/0	3/0	4/0									
225	1/0	2/0	1/0	2/0	3/0	4/0										
250	2/0	2/0	2/0	2/0	3/0	4/0										
275	3/0	3/0	3/0	3/0	4/0											
300	3/0	3/0	3/0	3/0	4/0											
325	4/0	4/0	4/0	4/0												

TABLE IS BASED ON APPROXIMATELY 3% VOLTAGE DROP.

TABLE IS BASED ON APPROXIMATELY 3% VOLTAGE DROP.

Solution: From table 2-9 read across from 40 amperes to 100 feet to find number 8, the wire size.

2-27. OUTLET BOXES

Electrical fixtures, switches and receptacles are never mounted directly

in the plaster, but are mounted in outlet boxes. To avoid shorting and crowding in the box, the number of wires running into a box is limited. The wire capacity of various sizes for typical boxes is listed below.

Box (Size in inches)		Maximum number of wires of wire size listed			
		No. 14	No. 12	No. 10	No. 8
1½ x 3¼	Octagon	5	5	4	0
1½ x 4	Octagon	8	7	6	5
1½ x 4	Square	11	9	7	5
1½ x 4-11/16	Square	16	12	10	8

2-28. CONDUITS AND FITTINGS

a. Conduit is thin, steel pipe which bends easily. It has smooth inside walls so wire insulation is not broken. Two types of conduits are the standard and the thin-walled. The number of wires allowable in various sized conduits is shown in table 2-11.

b. Condulets are small outlet boxes with threaded inlets to take conduit pipe (fig 2-19).

c. Bushings and locknuts are fittings used to dead-end conduits in standard outlet boxes (fig 2-19).

2-29. WIRE SPLICES

a. **Removing insulation.** Cut insulation the same as sharpening a pencil; remove it and clean wire. If outer braid covers wire, cut it 1 or 2 inches back of first cut and remove braid. Take care on last cut to cut only outer braid.

b. **Pigtail splice.** If wires are not under tension, they may be spliced by twisting them together in a pigtail as shown in figure 2-20.

c. **Western Union splice.** To splice two single-strand wires under tension, cross them

TABLE 2-11. Number of Wires Allowable In Various Sized Conduits

SIZE OF WIRE	NUMBER OF WIRES IN ONE CONDUIT								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	½	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	¾	1	1
12	½	½	½	¾	¾	1	1	1	1½
10	½	¾	¾	¾	1	1	1½	1½	1½
8	½	¾	1	1	1½	1½	1½	1½	1½
6	½	1	1½	1½	1½	1½	2	2	2
4	¾	1½	1½	1½	2	2	2	2	2½
2	¾	1½	1½	1½	2	2	2½	2½	2½
1	¾	1½	1½	2	2	2½	2½	3	3
1/0	1	1½	2	2	2½	2½	3	3	3
2/0	1	2	2	2½	2½	3	3	3	3½
3/0	1	2	2	2½	3	3	3	3½	3½
4/0	1½	2	2½	2½	3	3	3½	3½	4

RUBBER-COVERED OR WEATHERPROOF WIRE

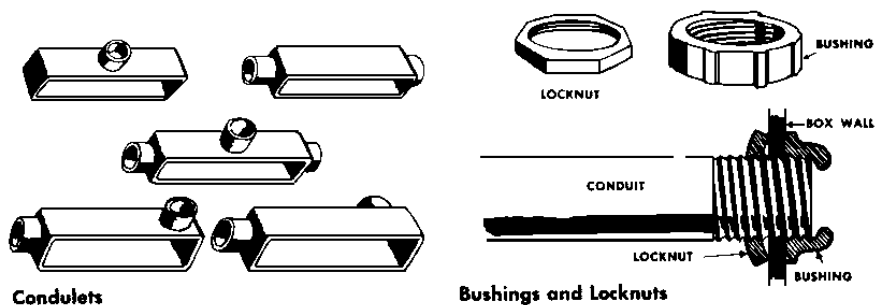


Figure 2-19. Conduit fittings.

(step 1) and then twist each wire at least five turns on the standing part of the other (step 2), as shown in figure 2-20.

d. Stranded splice. To splice stranded wires under tension, separate strands (step 1); push two end together (step 2); and wrap each strand separately around opposing strands (step 3). By carefully wrapping all strands, a neat, tight splice is made (fig 2-20).

2-30. SUPPORT INTERVAL

Wires must be supported at least every 4½ feet (fig 2-21). When

running wires, the first and last knobs on straight runs are partially set, wires between the knobs are pulled tight by hand, and the knobs are driven home. Other cleats or knobs are equally spaced between the first and last knobs of the straight run.

2-31. WIRING AND FIXTURE SYMBOLS

The symbols shown in table 2-12 are used in electrical details of TM 5-302, and other electrical drawings prepared by Office of Chief of Engineers. A standard set of sym-

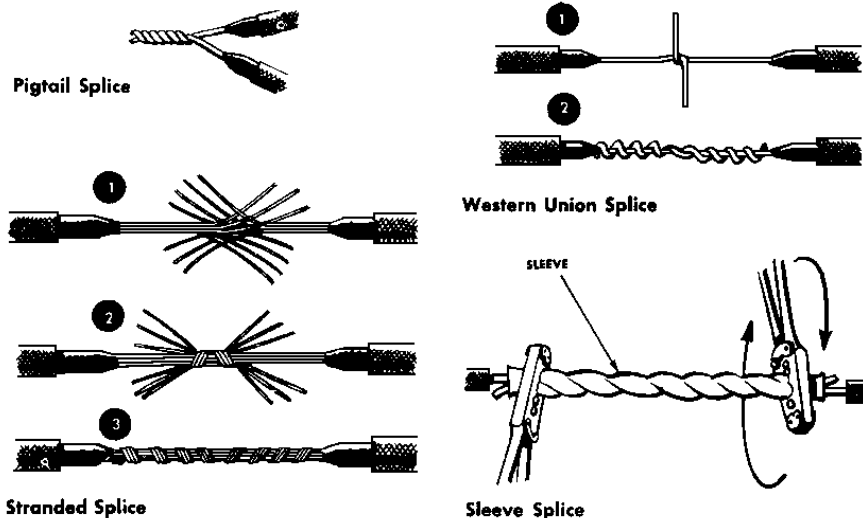


Figure 2-20. Wire splices.

TABLE 2-12. Wiring And Fixture Symbols

LEGEND		LEGEND	
1	Wiring concealed in ceiling or wall	1	Receptacle outlets**.
2	Wiring concealed in floor	1	Single outlet
3	Exposed branch circuit	18	Duplex outlet
4	Branch circuit home run to panel board (no. of arrows equals no. of circuits, designation identifies designation at panel)	19	Quadruplex outlet
5	Three or more wires (no. of cross lines equals no. of conductors two conductors indicated if not otherwise noted)	20	Special purpose outlet
6	Incoming service lines	21	20-amp, 250-volt outlet
7	Crossed conductors, not connected	22	Single floor outlet
8	Splice or soldered connection		Switches-
9	Cabled connector (solderless)	23	Single pole switch
10	Wire turned up	24	Double pole switch
11	Wire turned down	25	Three way switch
	Lighting outlets*	26	Switch and pilot lamp
12	Ceiling	27	Ceiling pull switch
13	Wall		Panel boards and related equipment-
14	Fluorescent fixture	28	Panel board and cabinet
15	Continuous row fluorescent fixture	29	Switchboard, control station or substation
16	Bare lamp fluorescent strip	30	Service switch or circuit breaker
		31	Externally operated disconnect switch
		32	Motor controller
			Miscellaneous-
		33	Telephone
		34	Thermostat
		35	Motor

*LETTERS ADDED TO SYMBOLS INDICATE SPECIAL TYPE OR USAGE

J - JUNCTION BOX R - RECESSED

L - LOW VOLTAGE X - EXIT LIGHT

**LETTER G NEXT TO SYMBOL INDICATES GROUNDING TYPE

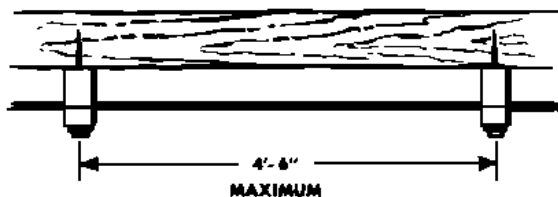
SPACING KNOBS, TUBES, AND CLEATS

Figure 2-21. Spacing of wire supports.

bols has not been set up to cover all commercial drawings. Symbols for wiring instructions included with various pieces of electrical equipment may vary.

2-32. ARMORED CABLE WIRING

Armored cable is used for special military installations, some theater-of-operations construction, and in

civilian work. It is safe and durable, but requires more time and materials to install than the knob-and-tube system.

a. Description of armored cable.

Common armored cable is a flexible wire consisting of two or more rubber-covered wires enclosed in a spiral-layed steel sheeting. Wires in the cable are different colors; in two-wire cables, one wire is black and the other white; in three-wire cables, the third wire is red. In armored cable and conduit wiring, the white wire is used as the neutral. The black and red wires are the hot wires. The white wire can serve as a hot wire when connected between three-way switches. When this is done, the ends of the white wire

should be painted black to indicate that they are not grounded. Cable size is designated by the number and size of the wires in the cable. For example, a cable carrying three No. 6 wires is known as a 6-3 cable.

b. Making connections. Splices are not permitted in armored cable wiring. All connections must be made inside outlet boxes. In making connections, always connect white to white, black to black, and red to red.

c. Supporting cable. Where cable runs across studs and joists, thread it through holes drilled in the center of the stud or staple it to a 1- by 2-inch runner. Where cable runs parallel to studs or joists, support it at least every 4½ feet by staples.

d. Making bends. To avoid kinking and cutting the cable, the radius of bends should not be less than five times the diameter of the cable.

e. Cutting cable. Use a hacksaw to cut cable armor. Place saw almost at right angles to strip or armor and cut through one strip. Take care not to cut wire insulation. To remove armor, twist it slightly and pull it off wire.

f. Armored cable or conduit to knob-and-tube wiring. Knob-and-tube wires are joined to another wiring

system within an outlet box. Wire entering the box must be protected by a loom. A special clamp can be used to connect armored cable and knob-and-tube wiring.

2-33. MOTORS

a. Rating. Motors are rated by horse-power, speed, and temperature. The name-plate on the motor gives this information as well as the operating voltages and currents and a wire-connection diagram.

b. Horsepower. The rated horsepower is the amount of power the motor can deliver continuously without damage to itself. For short periods, the motor can deliver more than its rated horsepower (table 2-13).

c. Speed. The speed is rated in revolutions per minute (rpm) while the motor is running at full load. Some motors are constant speed under load; other motors decrease speed as load is applied.

d. Temperature. Motors are rated on the temperature rise permitted above room temperature. The rated temperature is usually 100°F for general purpose motors. A motor with this temperature rating will be operating at 170°F in an ambient tempera-

TABLE 2-13. Full-Load Current and Circuit-Breaker Sizes for a-c Motor

MOTOR HORSEPOWER	SINGLE PHASE				THREE PHASE			
	110 VOLT		220 VOLT		220 VOLT		440 VOLT	
	CURRENT (AMPS)	CIRCUIT- BREAKER SIZE (AMPS)	CURRENT (AMPS)	CIRCUIT- BREAKER SIZE (AMPS)	CURRENT (AMPS)	CIRCUIT- BREAKER SIZE (AMPS)	CURRENT (AMPS)	CIRCUIT- BREAKER SIZE (AMPS)
1/8	3.34	15	1.67	15	—	—	—	—
1/4	4.8	15	2.4	15	—	—	—	—
1/2	7	15	3.5	15	2.5	15	1.3	15
3/4	9.4	25	4.7	15	2.8	15	1.4	15
1	11	25	5.5	15	3.3	15	1.7	15
1 1/4	13.2	35	6.6	25	4.7	15	2.4	15
2	20	50	10	25	6	15	3	15
3	28	50	14	35	9	25	4.5	15
5	44	70	22	50	15	35	7.5	15
7 1/2	66	125	33	70	22	50	11	25
10	86	200	43	70	27	50	14	35
15	—	—	—	—	38	70	19	50
20	—	—	—	—	52	125	26	70
25	—	—	—	—	64	125	32	70
30	—	—	—	—	77	125	39	70
40	—	—	—	—	101	200	51	125
50	—	—	—	—	125	200	63	125
60	—	—	—	—	149	225	75	125
75	—	—	—	—	180	400	90	200
100	—	—	—	—	246	400	123	200

ture of 70°F. The motor will be too hot to touch, but the running temperature of the motor will still be safe.

e. Stator and rotor. The stator is the stationary part of the motor. The rotor is the revolving part. The squirrel-cage rotor consists of a shaft on which are mounted laminated metal disks bound together by copper bars and soldered or welded to a copper ring at the end of the rotor. The wound rotor consists of a shaft on which are mounted laminated metal disks. Wire is wound in slots in the laminations. These wires are soldered to commutator bars on the end of the shaft. Brushes mounted on the stator contact the commutator bars when the motor is in operation.

2-34. MOTOR CARE AND MAINTENANCE

a. Dust. Fine particles of sand and dust settling on the moving parts of the motor scratch and groove bearing surfaces. Accumulated dust picks up oil forming a gummy mask that reduces the lubrication value of the oil, and plugs ventilation spaces. Periodically dust must be wiped off the motor and its moving parts. Dust can be blown out of the windings with compressed air at fairly low pressures (not over 40 psi).

b. Oil. Oil lubricates and protects moving parts of the motor. Oil must be kept in the bearings. Excess oil attacks the insulating material on wires and combines with dust to form a sticky gum that slows down the motor and causes sparking and shorting.

c. Removing oil and dust. Oil and dust must be wiped off periodically and the motor should be cleaned with a nonflammable solvent. The motor should be allowed to dry after oil and dirt are removed and the windings painted with insulating varnish.

d. Moisture. Moisture should be kept away from motors as much as possible. Moisture has two effects on motors:

(1) Soaked insulation is non-insulating, causing shorts in the motor.

(2) A combination of water and other elements rots insulating material and causes rust and corrosion.

e. Wear. Dirt and grit collecting on the commutator cause it to wear unevenly and produce faulty motor operation. A grooved commutator can be smoothed by running the motor at normal speed and holding 00 sandpaper against the commutator.

f. Undercutting mica. To stop excessive brush wear or sparking, the mica separating the commutator bars must be undercut about 1/32 of an inch. To undercut mica, grind a hacksaw blade to the thickness of the mica joint. Saw in the mic groove until the mica is cut approximately 1/32 of an inch below the surface of the commutator bar.

g. Emery cloth must never be used. The fine particles on the cloth are conductors and will short the motor.

h. Overload. Motors should never be required to pull a load higher than the rated capacity except for very short periods. Overloading heats the motor up and melts soldered joints or burns up insulation.

2-35. MOTOR EFFICIENCY

The nameplate of an electric motor gives the output of the motor in horsepower; that is, the amount of mechanical power the motor is able to deliver. The efficiency of a motor is the ratio of the output to the input expressed in percent and based on the following formula.

$$\text{Efficiency (in percent)} = \frac{\text{Output}}{\text{Input}} \times 100$$
$$\text{Output} = \text{Efficiency} \times \text{Input}$$
$$\text{Input} = \frac{\text{Output}}{\text{Efficiency}}$$

Loss of efficiency in an electric motor result from several causes including friction of the moving parts. In the process of producing power, the output of any electric motor is always less than 100 percent of the input. Input is expressed in watts; output usually in horsepower. One horsepower equals 746 watts. A motor with an output of 3 horse-power or 2,238 watts, with an efficiency of 85 percent, for example, will require an input of 2,632 watts:

$$\text{Input} = \frac{\text{Output}}{\text{Efficiency}}$$

$$\text{Input} = \frac{2,238}{.85} = 2,632 \text{ watts}$$

To find horsepower:

$$\text{Horsepower} = \frac{\text{watts}}{746} = \frac{2,632}{746} \text{ watts}$$

$$= 3.5 \text{ horsepower}$$

2-36. SAFETY PRECAUTIONS

a. Cut off power when working on circuits. Whenever possible, shut off power before starting work (dead circuit). To shut off power, main switches must be pulled and locked or tagged. Fuses can also be removed to prevent the circuits being energized while line work is in progress.

b. Test wires before starting work. All wires being worked on should be tested with a voltmeter or test lamp to determine whether or not they are energized.

c. Test lamp. A well-insulated weather-proof socket with 6- or 8-inch pigtails is often used to test circuits. Pigtails must be carefully insulated.

d. Never test circuit with fingers or tools. Bad burns and other injuries can result.

e. Insulated tools. Insulated tools such as pliers and screwdrivers are not certain protection for electricians working on energized lines. Taping plier and screwdriver handles does not insulate them.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space provided below each question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in the back of this booklet. Review the lesson as necessary. Do not send in your solutions to these review exercises.

1. Electricity is a form of energy. State the two methods by which it may be generated. (Para 2-2)

2. What electrical term is analogous to the term "gallons per minute" used in hydraulics? (Para 2-3f)

3. By the application of Ohm's law, what is the resistance in a circuit that has a voltage of 120 and an amperage of 7.5? (Para 2-4a)

4. If the voltage in an electric circuit remains constant, how can the flow of current, or amperage, be increased? (Para 2-4a(2))

5. What characteristic of single-phase current makes it unsuitable for operation of some motors? (Para 2-5d)
6. Electric power systems may have two, three, or four wires. Which system always carries single-phase current? (Para 2-6a)
7. What is the abbreviated notation used to designate a single-phase three-wire electrical power system with 120 volts between either hot wire and the neutral wire? (Para 2-6e)
8. Electrical fixtures can be connected in either series or parallel circuits. Which type circuit is most commonly used in wiring? (Para 2-8b)
9. If the primary coil of a transformer has 800 turns with 10 amps of current, and the secondary coil has 50 turns, what is the secondary current? (Para 2-9b)
10. Which type of transformer connection is used when there is a large single-phase load and a small three-phase load? (Para 2-13c(2)b)
11. What is the most common method used to vary the voltage output of a generator? (Paras 2-16b, 2-17b)
12. What is the maximum kilowatt capacity of single-phase generators normally available to the military? (Para 2-18a)
13. What one factor has the most influence upon the layout of an electrical distribution system? (Para 2-22)

14. What factor is of primary importance in determining the location of a generator, or generators, in an electrical power system? (Para 2-23a)

15. Normal small wire sizes range from number 40, the smallest to number 4/0, the largest. What size is normally used in building wiring? (Para 2-26a)

16. Referring to table 2-8, what wire size would you select to supply a 120 volt 60 ampere load at a distance of 75 feet? (Para 2-26d, table 2-8)

17. What is the maximum number of wires, size number 12, that you may run into a 1½-inch by 4-inch square outlet box? (Para 2-27)

18. What type splice is used to splice together two single-strand wires that will be under tension? (Para 2-29c)

19. No electric motor is 100 percent efficient. How is motor efficiency determined? (Para 2-35)

20. When work must be done on an electric circuit what is the first safety precaution to take? (Para 2-36a)

LESSON 3

REFRIGERATION SYSTEMS

CREDIT HOURS 2
TEXT ASSIGNMENT. Attached memorandum.
MATERIALS REQUIRED None.
LESSON OBJECTIVE Upon completion of this lesson on refrigeration you should be able to accomplish the following in the indicated topic areas.

1. **Basic theory.** Define heat and cold, explain the molecular theory, describe the different temperature scales and how to convert from one to another.
2. **Heat.** Explain measurement of heat, heat transfer, sensible heat and latent heat, and the measurement of refrigeration (ton).
3. **Application of principles.** Explain the effect and relationship of pressure, vacuum, insulation, and condensation upon the refrigeration process.
4. **Refrigerants.** State the designations and characteristics of the refrigerants most commonly used, giving the advantages and disadvantages of each.
5. **The vapor compression system.** Explain the theory and functioning of the vapor compression system to include the four essential parts of the system.
6. **The absorption system.** Define the basic elements of the absorption system and the theory upon which it functions.
7. **Operation and maintenance.** Explain the requirements for operating refrigeration systems, maintenance of the systems, and methods for detecting leaks in a refrigeration system.

ATTACHED MEMORANDUM

3-1. GENERAL

a. Most engineer officers and noncommissioned officers should have some knowledge of the fundamental principles of refrigeration. Engineers are responsible for the maintenance, repair, and methods of operation of fixed refrigeration equipment, and for the maintenance and repair of structures and utilities of refrigeration plants used for storage of subsistence.

b. Refrigeration deals with matter and energy. Therefore, you should

know the meaning of both. All things physical are composed of matter. Matter exists in only three forms: the solid form, the liquid form, and the gas form. On the other hand, energy is a measure of capacity for doing work.

c. Each substance is made of molecules. A molecule is the smallest particle that still retains the property of matter. Each molecule has the same weight as the other and all molecules behave exactly alike. The only difference between them as they exist in

their different states is due to energy, heat, and pressure.

3-2. HEAT

a. Heat. Heat is a form of energy. As a body absorbs heat, its molecules are receiving more energy, and as a result, vibrate faster. If all the heat is removed from a body, all molecular motion ceases.

b. Cold. Cold is a relative term used to explain the absence of some heat.

3-3. TEMPERATURE

a. Heat intensity. Temperature is defined as the heat intensity of a substance. Temperature is an indication of the degree of warmth, or the degree of "hotness" of a body.

b. Molecular theory. The molecular theory states that temperature is related to the average speed of the molecules in a body. It is important to avoid confusion between the terms heat and temperature. Temperature is a measure of the average speed of molecular motion, while heat (energy) is a measure of the total speed of all of the molecules present.

10lb of steel of 300°F	Bodies of Equal Temperature and Unequal Heat Content	5lb of steel of 300°F
---------------------------------	---	--------------------------------

The two bodies of steel (10lb and 5lb) have each been heated to 300°F. However, the smaller body possesses less heat (energy) than the larger piece of steel. More heat (and more time) is required to raise the larger body's temperature to 300°F.

3-4. TEMPERATURE SCALES

The most common temperature scale used in the U. S. is the Fahrenheit scale (fig 3-1). The centigrade scale is used primarily in the European and Asiatic countries. The Fahrenheit scale is the one most used in the refrigeration industry.

a. Fahrenheit temperature. The Fahrenheit scale is so fixed that it divides the temperature difference from the melting temperature of ice to the boiling temperature of water into 180 equal divisions and sets the melting point of ice at 32 divisions

above the zero on the scale. Therefore, ice melts at 32°F and water boils at 212°F (180° + 32°F) assuming standard atmospheric pressures.

b. Centigrade temperature. The centigrade scale has wider divisions than the Fahrenheit scale and the zero (0°C) of this scale is set as the melting temperature of ice. The boiling point of water is fixed 100 divisions above 0°C or at 100°C assuming standard atmospheric pressure.

3-5. ABSOLUTE TEMPERATURE SCALES

The point at which all molecular motion ceases due to the removal of all the heat is called absolute zero. Zero degrees on the absolute scale is called absolute zero and is equal to -460°F or -273°C. When dealing with the absolute scales we refer to the temperature as Fahrenheit Absolute (FA) or Centigrade Absolute (CA) (fig 3-1). To convert the boiling point of water (212°F) to FA (Fahrenheit Absolute) merely add 460. Water boils at 672°F.

The formula is: °FA = 460 + °F. To convert the boiling point of water (100°C) to CA (Centigrade Absolute) merely add 273. Water boils at 373°C.

The formula is: °CA = 273 + °C.

3-6. FAHRENHEIT -- CENTIGRADE CONVERSION

Sometimes it will be necessary to convert Fahrenheit temperatures to centigrade or vice-versa. Two very simple formulas have been developed for these conversions. **Remember them.**

a. Fahrenheit to Centigrade

$$(^{\circ}\text{F} - 32)$$

$$^{\circ}\text{C} = \frac{\quad}{1.8}$$

$$1.8$$

Example: Given 52°F, find °C.

$$(^{\circ}\text{F} - 32)$$

$$^{\circ}\text{C} = \frac{\quad}{1.8}$$

$$1.8$$

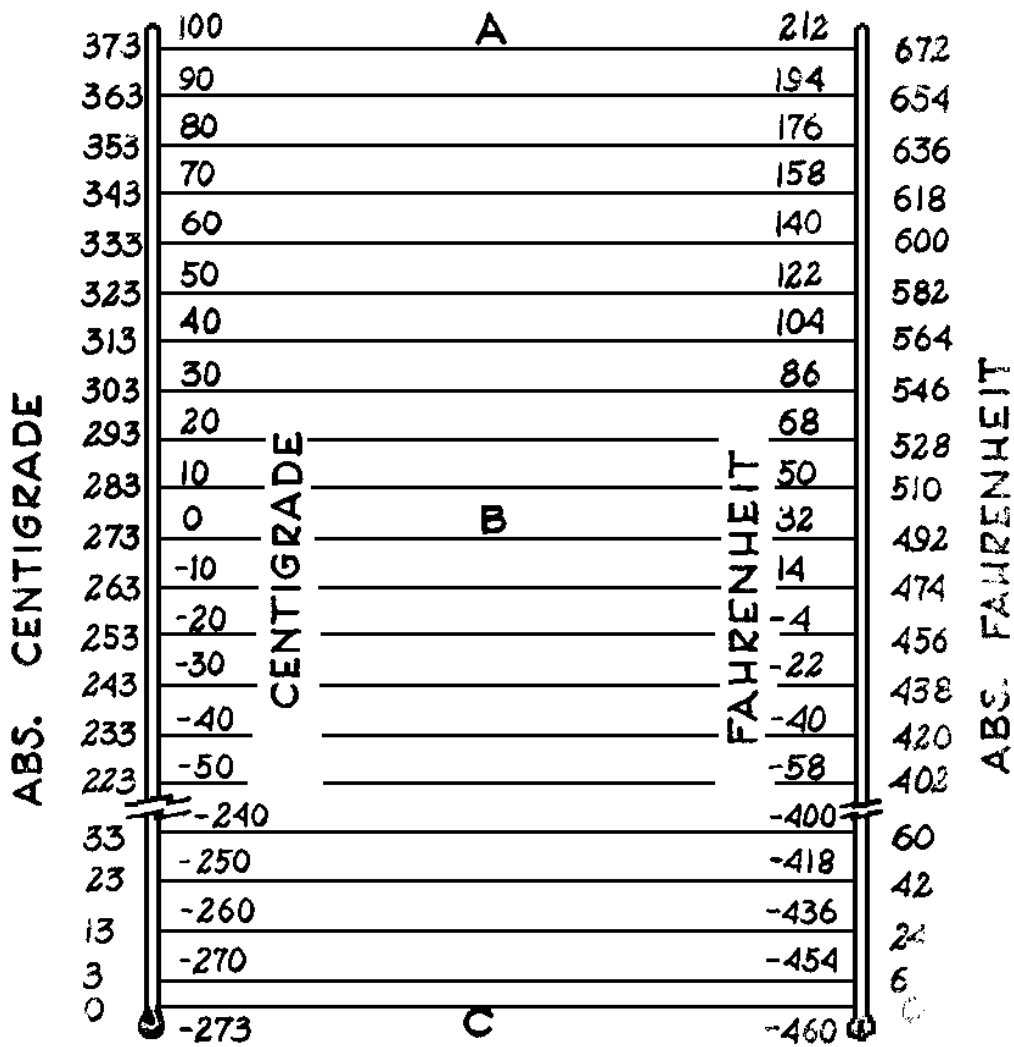
$$(52 - 32) \quad 20$$

$$^{\circ}\text{C} = \frac{\quad}{1.8} = \frac{\quad}{1.8}$$

$$1.8$$

$$1.8$$

$$^{\circ}\text{C} = 11.2 = 11^{\circ}\text{C}$$



A = BOILING TEMP. OF WATER AT ATMOSPHERIC PRESSURE
 B = FREEZING TEMP. OF WATER AT ATMOSPHERIC PRESSURE
 C = ABSOLUTE ZERO TEMPERATURE

Figure 3-1. Four standard temperature scales and their relationship.

b. Centigrade to Fahrenheit

$$^{\circ}\text{F} = 1.8 (^{\circ}\text{C}) + 32$$

Example: Given 10°C , find $^{\circ}\text{F}$.

$$^{\circ}\text{F} = 1.8 (^{\circ}\text{C}) + 32$$

$$^{\circ}\text{F} = 1.8 (10^{\circ}) + 32$$

$$^{\circ}\text{F} = 18 + 32$$

$$^{\circ}\text{F} = 50$$

Figure 3-1 shows a comparison of the four scales we have discussed: Fahrenheit, Centi-

grade, Fahrenheit Absolute, and Centigrade Absolute.

3-7. BRITISH THERMAL UNIT (BTU)

Temperature is measured in degrees with the use of a thermometer. Heat quantity is measured in British thermal units (Btu). A Btu is defined as the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit (fig 3-2).

3-8. HEAT TRANSFER

If the temperatures of two substances are unequal, heat flows from the hot substance to the cold one. Transfer of heat takes place by conduction, convection, and radiation.

a. Conduction is the flow of heat from one part of a substance to another part of the same substance or from one substance to another substance in direct contact with it. A piece of iron with one end placed in a fire will soon become hot end to end. This is an example of heat transfer by conduction.

b. Convection is the conveying of heat from one point to another by the movement of some easily circulated medium such as air. A common example of this is the movement of heat-laden air from a furnace into the rooms of a house where it releases its heat and then returns through the return air duct.

c. Radiation is the transfer of heat by heat rays. Examples of this are the heat from the sun and the heat felt near a flame. It should be understood that heat rays do not heat the air through which they pass. They heat only the surfaces which they strike.

3-9. SENSIBLE HEAT

Sensible heat is heat added to a substance causing a rise in temperatures but no change in state. That is, any change in heat which causes a change in temperature only is called sensible heat.

3-10. LATENT HEAT

The heat energy required to change the state of a substance without changing its temperature is latent heat. Changing the state of a substance is accomplished by adding or subtracting heat. When water is boiled and then further heated, it changes to steam (evaporates). When steam is cooled (heat is removed) sufficiently, it changes back to liquid (condenses). When water is cooled sufficiently, it freezes and changes back to ice.

3-11. LATENT HEAT OF VAPORIZATION

Latent heat of vaporization is the amount of heat which must be added to 1 pound of a

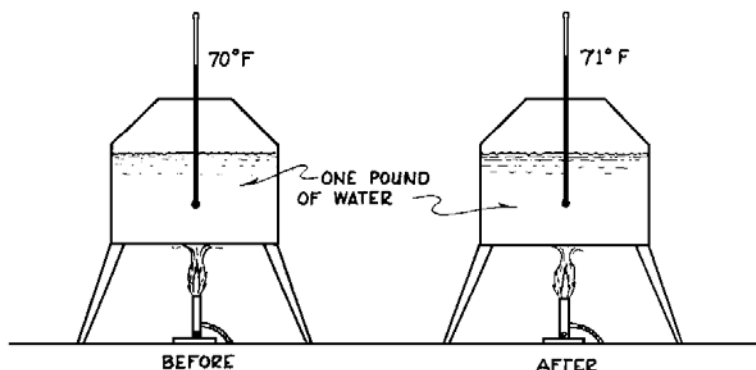


Figure 3-2. The addition of one British thermal unit.

liquid substance to cause it to evaporate completely to a gas. For example, water can be heated to 212°F and not boil. After water reaches 212°F, 970 Btu of heat per pound of water must be added to convert it to steam. The temperature of the steam will also be 212°F. The liquid is converted to a vapor without change in temperature. Latent heat of vaporization of water is 970 Btu.

3-12. LATENT HEAT OF FUSION

Latent heat of fusion is the amount of heat which must be removed from 1 pound of a liquid substance to cause it to freeze completely to a solid state with no change in temperature. For example, 144 Btu are removed to freeze 1 pound of water at 32°F to ice at 32°F. Conversely, the addition of 144 Btu will cause the melting of ice at 32°F to water at 32°F.

3-13. PRESSURE

a. General. Pressure is the amount of force exerted on a substance per unit of area. It is normally expressed in terms of pounds per square inch (psi) and is calculated by dividing the total force acting on a substance by the total area on which it acts.

$$\text{Pressure (P)} = \frac{\text{Force in lb (F)}}{\text{Area in sq inches or sq feet (A)}}$$

b. Atmospheric pressure.

Atmospheric pressure is pressure at sea level. It is expressed as 14.7 pounds per square inch absolute pressure, or 29.2 inches barometric (mercury column) pressure. As one ascends a hill, the atmospheric pressure will decrease; but below sea level in excavations or depressions, it will increase.

c. Gage pressure. Gage pressure (PSIG) is used on all ordinary gage scales. They read zero at atmospheric pressure, and measure pressures above and below atmospheric.

d. Absolute pressure. Absolute pressure (PSIA) is gage pressure plus 14.7.

Example:

Absolute Pressure = Gage Pressure + 14.7

$$\begin{array}{ccc} & \text{(PSIA)} & \text{(PSIG)} \\ \text{Gage Pressure} & = & \text{Absolute Pressure} - 14.7 \\ & \text{(PSIG)} & \text{(PSIA)} \end{array}$$

e. Effects of pressure.

(1) On volume. The exertion of pressure on a substance will decrease its volume in proportion to the increase of pressure. Three cubic feet of gas is placed in a cylinder, and a piston exerting a pressure of 60 pounds per square inch is inserted in the open end. If the piston is pushed down into the cylinder and compresses the gas into 1 cubic foot, the pressure exerted would have to be 180 pounds per square inch. If the piston were withdrawn so that there were 6 cubic feet of the gas, the pressure would shrink to 30 pounds per square inch (fig 3-3).

(2) On vaporization.

Vaporization is the process of changing a liquid to a vapor, either by boiling or evaporation. Evaporation takes place only at the surface of a liquid. Boiling takes place throughout the interior of the liquid. Absorption of heat by a liquid causes boiling and evaporation. Reduced pressure lowers the boiling point of a liquid. Increased pressure raises the boiling temperature. For every given pressure acting on a liquid, there is a corresponding temperature at which the liquid will boil. Reduction of pressure on a liquid lowers the temperature at which evaporation takes place. When a liquid evaporates, it absorbs heat from warmer surrounding objects and atmosphere. This is the basic principle of refrigeration.

(3) On temperature. Absolute pressure of a confined gas at constant volume is proportional to absolute temperature. Thus, if a given volume of gas is confined in a container and subjected to changes in temperature, the pressure of the gas will change so the quotient of pressure divided by absolute temperature is always the same.

Note: A cylinder containing a given weight of liquid varies in volume of liquid and volume of gas with changes in temperature.

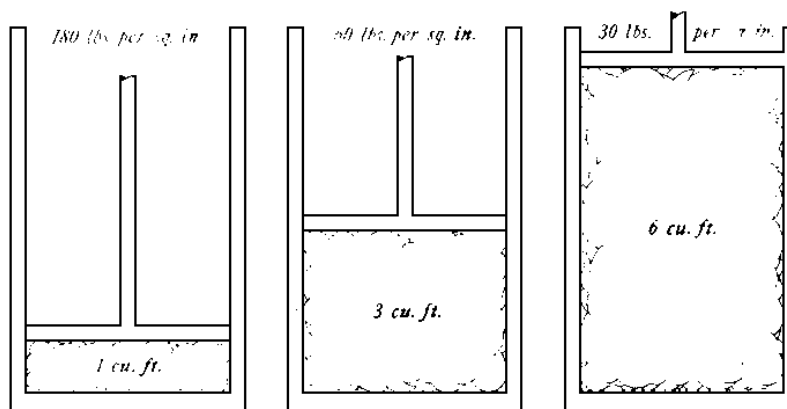


Figure 3-3. Effect of pressure on volume.

3-14. CONDENSATION

Condensation is the process of changing a vapor to a liquid. Removal of heat from a vapor causes it to condense. Increase in pressure on a vapor causes it to condense. Condensing vapor gives up its heat to cooler surroundings and the atmosphere.

3-15. VACUUM

When air is exhausted from a sealed container, pressure within the container is reduced below atmospheric pressure and a partial vacuum is formed. Any pressure below atmospheric pressure (14.7 psi) is indicated in inches on the vacuum gage. Each 2 inches of vacuum is equal to approximately 1 psi below atmospheric pressure.

3-16. THE "TON" OF REFRIGERATION

a. The unit of capacity for measurement of refrigeration equipment is the "ton". This is defined as the amount of heat absorbed in melting 1 ton (2000 lbs) of ice in 24 hours. It requires 144 Btu (latent heat of fusion) to melt 1 pound of ice at 32°F to water at 32°F. Consequently, in order to melt a ton of ice, 2,000 x 144, or 288,000 Btu would be required. If this capacity is spread over 24 hours, the capacity of such a machine would be 288,000 ÷ 24, or 12,000 Btu per hour. The capacity changes somewhat with the operating conditions. Therefore, in order to

have a basis for comparing different machines with each other, conditions under which the standard ton of refrigeration should be measured have been defined as follows:

(1) Inlet pressure. Suction or back pressure corresponding to an evaporator gas temperature of 5°F.

(2) Outlet pressure. A discharge or head pressure, corresponding to a condensing gas temperature of 86°F.

b. In addition, the definition also specifies the number of degrees of superheat that the gas should have when it enters the condensing unit, and the number of degrees of subcooling that the liquid should have when it leaves the condensing unit. However, for our purpose, we may think of a standard ton of refrigeration as simply the refrigerating capacity of 12,000 Btu per hour.

Note: A ton of refrigeration does not necessarily equal one horse-power.

3-17. INSULATION

a. Principles.

(1) There would be little practical value in removing heat from a body if the rapid flow of heat back into it could not be prevented. Efficient insulation is as important to the overall economy of a refrigerating plant as efficient heat removal. The walls of storage spaces should be constructed in such a manner as to prevent the transfer of heat

from outside sources. Pipes carrying brine or other refrigerants should be covered to keep these cooling elements from absorbing heat before they reach the area or substance to be refrigerated. Various substances which make good insulators are available. Most of the insulators in use owe their value to the fact that they contain an enormous number of tiny air cells. Air is a poor conductor, and its circulation is reduced to a minimum by the smallness of each air cell. Air must be confined in very small cells to be effective as an insulator; for when it is confined merely between two walls where convection currents may be set up, it has comparatively little insulating value. Should moisture from the air find its way into the air cells and freeze there, the insulation value is reduced because the poor conductor, air, is replaced by a solid, ice, having better conductivity. Expansion in process of freezing collapses adjoining cells, and disintegration of the insulation progressively results. For this reason, insulation should be well protected against the infiltration of moisture.

(2) Of whatever material the insulation is made, its value is largely governed by the method of installation. Sheet and board material should be applied in two or more layers with staggered joints, and tightly cemented together and to the walls, ceiling, or floor. The outer surfaces should always be vapor-proofed, cement plaster or sheathing being the usual finishing material on the interior. The tightness of doors and other openings in cold storage is a big factor in the efficiency of the plant. The thickness of insulation used depends upon the operating temperatures, the exposure of the walls and ceiling to external heat, and the difference between the air outside the compartment and that inside (heathead).

(3) The insulation must have sufficient strength to support itself and not shrink or settle. It must not deteriorate in the presence of moisture, must not have any unpleasant odor, and must be vermin proof. The type of insulation depends on the method of application. For example, bulk easy flowing insulation can be placed between the studs or panels of the warehouse, while rigid insulation can be

used as a part of the warehouse wall, such as plaster base or as a substitute for the ship lap sheeting. Flexible insulation is easily installed and conforms to any irregularities in the construction. Batts of rock wool and blankets of pulverized wood are examples of this practice. It is exceedingly important that all insulations that are hygroscopic (moisture absorbent) be hermetically sealed. Even those insulations not affected by moisture should be vapor sealed, as the insulation will lose much of its insulating value if it should become saturated with moisture. To reiterate, the most serious problem with any insulation is to keep the insulation dry. The moisture that can collect in insulation is always present in the air. When the air on one side of a structure contains more moisture than the air on the other, the pressure difference (vapor pressure) is quite high. The moisture will then seek its way through the smallest opening and condense on the colder area if the temperature is below the dew point temperature. Research organizations throughout the world have experimented to determine the factor of heat leakage through walls, and refrigeration companies have spent considerable time perfecting means whereby we can be absolutely sure of the quantity of heat that leaks into a definite kind of cold storage warehouse for refrigeration. The longer the factor, the more heat will leak through an insulated wall. The standard time used for computation is the 24-hour period. The difference in temperature is an important factor in the heat leakage of a container. The greater the temperature difference the more heat will leak through the wall. The thicker the insulation, the less heat loss; twice as much heat will leak through a wall that is insulated with 1 inch of insulation as will flow through a wall having 2 inches of insulation. The type of insulation or the material used is one of the most important considerations in the construction of cold storage warehouses. Cork, for instance, will insulate approximately four times better than wood and eight or nine times better than brick; on the other hand, some insulation is more costly than others and this must be taken into considera-

tion. The larger the external area of a cabinet through which heat may transmit a leak, the greater the heat flow. The common unit for determining heat flow through a cabinet wall is the square foot of area. The area is always taken as the outside of the cabinet or warehouse. To bring together the variables just mentioned, standards have been developed and are now being used by the various refrigerating companies. The variables have been reduced to unit values, and the heat leakage of the wall is first determined for the unit values. The unit or basic values are obtained from a slab of the insulation 1 square foot in area, 1 inch thick, with a temperature difference of 1°F over a period of time of either 1 hour or 24 hours. The values obtained represent the heat flow through the slab under the condition and naturally vary with the kind of insulation. This material has no air film or liquid film on either side. Insulation has this characteristic due to the fact that it contains millions of dead air cells. The ability to resist heat is commonly known as "K" factor. This factor is used to compute the heat leakage through a composite wall, such as a wall made out of wood, cork, or metal.

b. Materials used for insulation.

(1) Very few materials meet all the requirements of an ideal insulator for refrigeration purposes. Some in common use are pumice, animal wool (in the form of hair felt), mineral and rock wool, waterproof paper, metal foil sheets, redwood bark, kapok, rock cork, and vegetable cork in granulated and board form. In stationary cold-storage plants such materials are used in conjunction with thick walls of brick, hollow tile, dead-air space, etc. In walls, a dead-air space large enough to allow circulation of air was at one time considered a highly efficient and cheap form of insulation; but this method has now been entirely discarded. Aluminum foil and many patented materials are used to insulate truck bodies. But practically every insulating material now used encloses air in cavities small enough to prevent any circulation. This gives lightness to the material, a factor that is of prime importance particularly in insulation of transportation equipment.

(2) Mineral wool is made from the slag of blast furnaces with lime-stone added. The crushed rock is mixed with coke and fed into furnaces at a temperature of about 3,000°F. As the mol-tten slag runs from the furnace, it is blown by high-pressure steam into a fleece-like fluff through brittle mass.

(3) Rock cotton, or rock wool, is made as in (2) above, except that granite and limestone are used. From 92 to 96 percent of the bulk of the finished wool consists of tiny air spaces. The wool is made into slabs about 1 or 2 inches thick.

(4) Vegetable cork is the most efficient and most commonly used insulating material for permanent installations. It is commonly used in the form of slabs, of 1-, 2-, or 3-inch thicknesses, and of varying width and length. It is prepared by cementing cork granules together under pressure by baking or by the use of cement. In this form, if properly installed, it more nearly meets all the requirements of a perfect insulating material than any other material. It is light in weight, is a nonconductor of heat, and resists action of fire and moisture.

(5) The relative values of various insulating or non-heat-conducting materials (dry material, in thicknesses of 1 inch, 1 square foot of surface with a 1° differential), are listed herewith; the rating is in Btu per hr.

Material	Btu
Cork sheets, pure .....	.270
Cork sheet, asphalt cemented ..	.300
Air space	1.10
Rock wool .....	.280
Pine, white .....	.78
Oak, red	1.03
Pine, yellow	1.00
Brick wall	5.00

3-18. REFRIGERANTS

a. Definition. That body, gas, or liquid which reduces heat is a refrigerant.

b. Principles. The principles of mechanical refrigeration are based upon the ability of refrigerants to absorb heat while in the process of changing from solids to liquids and from liquids to gases. Also, after those

gases have been boiled from a liquid and have picked up all their latent heat of vaporization, they can be compressed by control of pressures, and condensed by removing the heat of compression and vaporization. Thus, they return to their liquid state and assume their heat absorptive ability.

c. Requirements. There are certain desirable characteristics which a fluid used as a refrigerant should possess. They are:

- (1) Nonpoisonous.
- (2) Nonexplosive.
- (3) Nontoxic.
- (4) Noncorrosive.
- (5) Nonflammable.
- (6) Leaks should be easy to detect.
- (7) Leaks should be easy to locate.
- (8) No undesirable action with oil.
- (9) Should operate under low pressure.
- (10) Should be a stable gas.
- (11) Should have a small relative displacement to obtain a certain refrigeration effect.
- (12) Should have a well-balanced latent heat evaporation value per unit of weight.
- (13) Should have a minimum difference between the vaporizing pressure and the condensing pressure.

d. Classification of refrigerants. Refrigerants have been classified by two different national groups. They are the National Refrigeration Safety Code and the National Board of Fire Underwriters. The National Refrigeration Safety Code divides all refrigerants into three groups listing group I the safest, group II toxic and somewhat flammable, and group III as a very flammable refrigerant. The National Board of Fire Underwriters has similarly classified refrigerants based mainly on their degree of toxicity. There are six divisions in this scale. Class 1 is the most toxic while class 6 is the least toxic.

e. Common refrigerants. R-12, R-22, and R-113 are good refrigerants for air conditioning. They operate at moderate pressures and are easily handled.

(1) R-12 (Dichlorodifluoromethane) is a colorless, almost odorless gas

with a boiling-point of -21°F at atmospheric pressure. It is nontoxic, noncorrosive, nonirritating, and nonflammable. It is generally prepared by replacing chlorine in carbon tetrachloride with fluorine. Chemically it is inert at ordinary temperatures and thermally stable up to 1022°F . R-12 has a relatively low latent heat value and this is a decided advantage in the smaller refrigerating machines, because the large quantity of liquid circulated will permit the use of less sensitive, more accurate, and more positive operating and regulating mechanisms. It operates at a low but positive head and back pressure, and with a good volumetric efficiency. It is only slightly soluble in water, and the solution formed is very slightly corrosive to any of the common metals used in refrigerator construction. The addition of mineral oil to the gas has no effect upon the corrosive action, except possible to decrease the amount of discoloration caused by the free water. It has the following characteristics:

- (a) Nonflammable.
- (b) Nonexplosive.
- (c) Nonirritating.
- (d) Nontoxic.
- (e) No odor even in fairly high concentrations.
- (f) Stable.
- (g) Noncorrosive.
- (h) No effect on flowers, fruits, vegetables, dairy products, furs, or other materials being refrigerated.

(2) R-22 (Monochlorodifluoromethane) refrigerant is a synthetic chemical specially developed for those refrigeration installations that have a very low temperature cooling unit. One example of this application is in fast freezing units which maintain a temperature of -20°F to -40°F . The operating pressures of this refrigerant are such that it is not necessary to operate at below atmospheric pressures in order to obtain these low temperatures. The boiling point is -41°F at atmospheric pressure. It has a latent heat of

93.6 Btu per pound at 5°F. The normal pressure at 86°F is 160 psi. This refrigerant is very stable and is nontoxic, noncorrosive, nonirritating, and nonflammable. Water is more soluble in R-22 than R-12 by a ratio of 40:1. Water must be kept at a minimum in these refrigerants, so dryers or dessicants are used to remove most of the moisture. Because of R-22's affinity for water more dessicant is needed to dry it.

(3) R-113 (Trichlorotrifluoromethane CCl₂ FCCIF₂) is a low pressure refrigerant that is used chiefly with centrifugal compressor in air conditioning systems of large tonnage capacity. At 5°F it evaporates at 27.92 inches vacuum, the gas occupies 27.04 cubic feet per pound, and the latent heat is 70.62 Btu per pound. At 86°F the refrigerant condenses at 13.93 inches vacuum. R-33 can be tested for leaks by warming the refrigerant to 200°F, which will produce a pressure of 39.96 psi. A halide torch or an electronic leaf detector is then used. At room temperature and pressure the refrigerant is a liquid and it can therefore be carried in sealed tins rather than in cylinders. It is classed as a Group I refrigerant as to fire safety, and as a Class 4 refrigerant as to toxicity.

f. Changing refrigerants. It is not recommended that refrigerants be changed in a machine that has been designed for a particular refrigerant. However, if this has to be done in extreme cases, the following pointers may prevent considerable trouble. In general, it is best to use expansion valves and a dry system when substituting refrigerant, rather than attempt to recalibrate float controls.

Also it should be remembered that many small engineering features that are incorporated in a unit to promote efficiency for the particular refrigerant selected will be lost if a change in the refrigerant is made.

g. Refrigerant sight glass. This device is merely a short length of tubing containing a transparent section of glass. The sight glass, inserted in a liquid line, enables the maintenance man to determine the state of the refrigerant at a glance. The passing liquid should always

appear clear. A cloudy or bubbly flow is usually indicative of an undercharge of refrigerant.

3-19. LEAK DETECTION

a. Principles. In order for a refrigeration unit to operate efficiently it must remain perfectly sealed. Not only must the refrigerant be held within the system, but air and moisture must be kept out. If a leak occurs the refrigerant will escape to the atmosphere. The most common cause of leaks can be traced directly to poor workmanship; improper flaring and soldering as well as aging and loose connections. Two other causes of leaks which can be traced to normal operation are vibration and normal wear due to friction, heat, etc. Vibrations from the compressor motor are transmitted throughout the system by the rigid tubing used to carry the refrigerant from one component part to another. Very little can be done about vibration other than the installation of shock absorbers at critical points. The number of problems created by normal wear can be cut down by periodical maintenance. Units may come from the manufacturer in a defective condition or they may be damaged in shipment. It is important to thoroughly check all units upon receipt from the manufacturer or after movement from one point to another.

b. Methods of leak detection. There are three methods used in leak detection. They are classified as positive, non-positive, or special.

(1) Positive detection methods. A positive leak detection method is one that not only determines if a leak is present, but also indicates the exact location. Two commonly used positive methods are the oil bath and soap bubble method. Oil or a soapy water solution is spread on the unit, particularly around fittings. If a leak is present, bubbles will appear indicating its exact location.

(2) Nonpositive detection methods. A nonpositive leak detection method indicates the presence of a leak, but it does not give the leak's exact location. Two nonpositive leak detection methods are the pressure and vacuum tests. In the pressure test a positive pressure is built up in the system and a

reading is taken. After 24 hours another reading is taken; any drop in pressure from the first reading will indicate the existence of a leak. In the vacuum test a vacuum is drawn on the system; any rise in pressure over 24 hours will indicate a leak.

(3) Special detection methods.

There are quite a number of special detection methods in use. The popular special method is the halide torch. The torch is lit and the alcohol or acetylene flame is passed over the areas where the leak is suspected. If a small leak is detected, the flue flame will turn green and if a large leak is present the flame will turn violet. The halide torch can be used with any units charged with halogen type refrigerants (R-12, R-22, etc) or with methyl chloride. For proper results, it is important to remember that the torch must be adjusted to produce a small flame. The ammonia swab may be used to detect leaks in units charged with sulfur dioxide. A cotton swab is soaked in ammonia and passed over the system. If a leak is present the uniting of the ammonia fumes with those of the sulfur dioxide will produce a dense white smoke. The sulfur stick and pink litmus paper tests may be used with systems charged with ammonia. The sulfur stick is lit and passed over the unit. If a leak is present the uniting of the fumes will produce a dense white smoke. The litmus paper method is used on ice plants where ammonia is the refrigerant used. The pink litmus paper is placed in the secondary refrigerant (water). The paper will turn from its natural pink color to blue if a leak is present.

3-20. APPLICATION OF PRINCIPLES

a. Principle. Refrigeration by the vaporization of liquids and gases is based upon the fact that, in the absorption of heat units from a substance the refrigerant boils into a gas and continue, to absorb heat units in expansion. After the gas is expanded, it is compressed, cooled, and condensed back into a liquid, and is then ready for reuse.

b. Effect of temperature on gases.

For illustration, ammonia is used. Figure 3-4 is a sketch of liquid ammonia (NH₃) in an open flask whose base is inserted into an insulated compartment. Since the boiling point of ammonia is at -28°F , it will remain inert if the insulated compartment temperature is at -28°F . But should the temperature rise even 1° , the ammonia would begin to boil or vaporize, absorbing about 591 Btu. Now if the temperature of the insulated compartment rises up to 0°F , the ammonia will boil violently, absorbing about 618 Btu, until the compartment temperature is lowered to -28°F .

c. Effect of pressure on liquids and gases. In figure 3-5 the flask with ammonia has a stopper in the neck and a valve which can be turned on and off. The figure illustrates the effect of pressure on the vaporization of ammonia gas. In the first sketch, the valve is open and the ammonia boils away, until the compartment is cooled down to -28°F . However, it is desired that the compartment temperature be cooled only to 0°F instead of -28°F . In this case, the valve

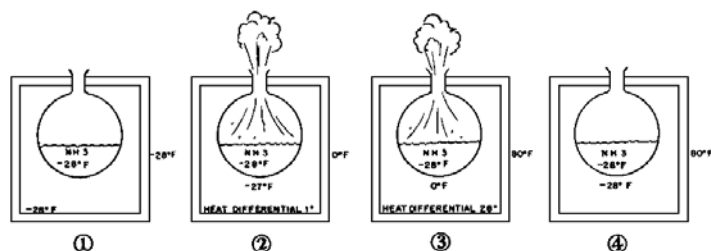


Figure 3-4. Reaction of liquid ammonia at atmospheric pressure.

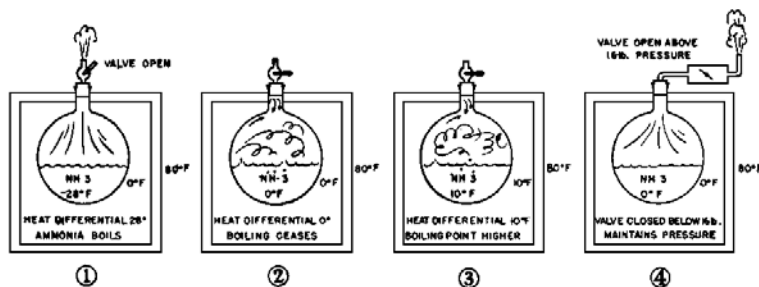


Figure 3-5. Reaction of liquid ammonia under pressure.

is closed, and as the gas vaporizes, it continues to absorb heat units which cause it to expand. The expansion confined in the flask causes the pressure to increase, which in turn causes the boiling point of the ammonia to rise. Consequently, when the pressure has reached 16 pounds gage, the boiling point of the liquid ammonia will be at 0°F. When the temperature of the compartment reaches 0°F, the liquid will cease boiling and become inactive until the pressure drops or the temperature goes up. It can now be seen that the increase in pressure has raised the boiling point of the ammonia. The pressure increases in the flask, however, must be controlled if the temperature in the insulated compartment is to be controlled. No consideration has been given to the fact that the pressure in the flask might become greater than 16 pounds gage, in which case the boiling point of the liquid ammonia would rise to a higher temperature. In the third sketch, the pressure has reached 25 pounds gage and the boiling point at this pressure is at 10°F. However, if the valve is set to open with pressure above 16 pounds gage and to close under 16 pounds gage, the flask pressure would be maintained at 16 pounds gage and the ammonia would absorb heat units as long as temperatures above 0°F prevailed in the compartment. The behavior of ammonia has been plotted for a wide range of pressures as shown in figure 3-6.

3-21. THE VAPOR COMPRESSION SYSTEM

a. Principle. Mechanical refrigeration utilizes the properties and characteristics of refrigerants described above, and by controlling the action of the refrigerant and inclosing it in a system, can cool substances and areas to within a few degrees of the desired temperatures. The vapor compression cycle includes the compression and condensing of certain gases, which in evaporating, absorb heat from an area or substance and in turn give up that heat when cooled and condensed. There are four essential or basic parts of the vapor compression system: evaporator, compressor, condenser, and expansion valve. This does not include the various other valves, gages, pipes and fittings.

b. Equipment and functions (fig 3-7).

(1) The evaporator is where the refrigerant boils in absorbing heat. It is often called the freezer and it does the same job as the flask of ammonia discussed above. The evaporator is located in the space where cooling is to be accomplished, and is arranged to provide for natural or forced circulation of the refrigerant or heat carrier. Once the refrigerant vapor is drawn out of the evaporator, all we have to do is remove the heat it has absorbed. Since heat is the only thing that expanded the refrigerant from a liquid to

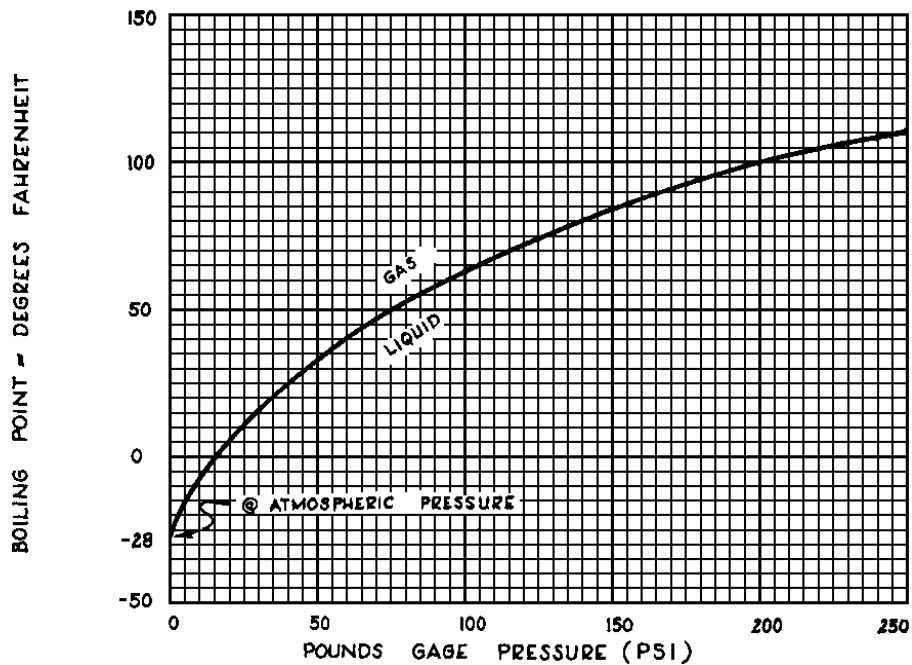


Figure 3-6. Ammonia pressure vs temperature.

a vapor, removal of that same heat will allow the vapor to condense back to a liquid again.

(2) The compressor squeezes the heat-laden vapor into a smaller space, concentrating, at the same time, the heat it contains. In this way, the vapor is made hotter without adding any heat. That is the only responsibility of a compressor in a refrigerating system. It is not intended to be a pump just for circulating the refrigerant. Rather, the compressor's job is to exert pressure for two reasons. Pressure makes the vapor hot enough to cool off in warm room air. At the same time, the compressor raises the refrigerant's pressure above the condensing point at the temperature of the room air so it will condense.

(3) The condenser is where the latent heat in the vapor is given up. As the refrigerant leaves the

compressor, it is still a vapor although it is now quite hot and ready to give up the heat it has carried out of the cabinet. The condenser is a very simple device having no moving parts. It does exactly the same job as the familiar radiator in a typical home steam heating system. There, the steam is nothing more than water vapor. In passing through the radiator, the steam gives up its heat and condenses back into water. The condenser and compressor will vary in size with the volume of refrigeration desired.

(4) The receiver, whether integral with or separate from the condenser, acts as a surge reservoir to supply needed refrigerant or to accumulate excess refrigerant. The usual method is the use of the separate tank as shown in figure 3-7. The liquid receiver is provided with a gage glass so that the quantity of liquid refrigerant may be readily

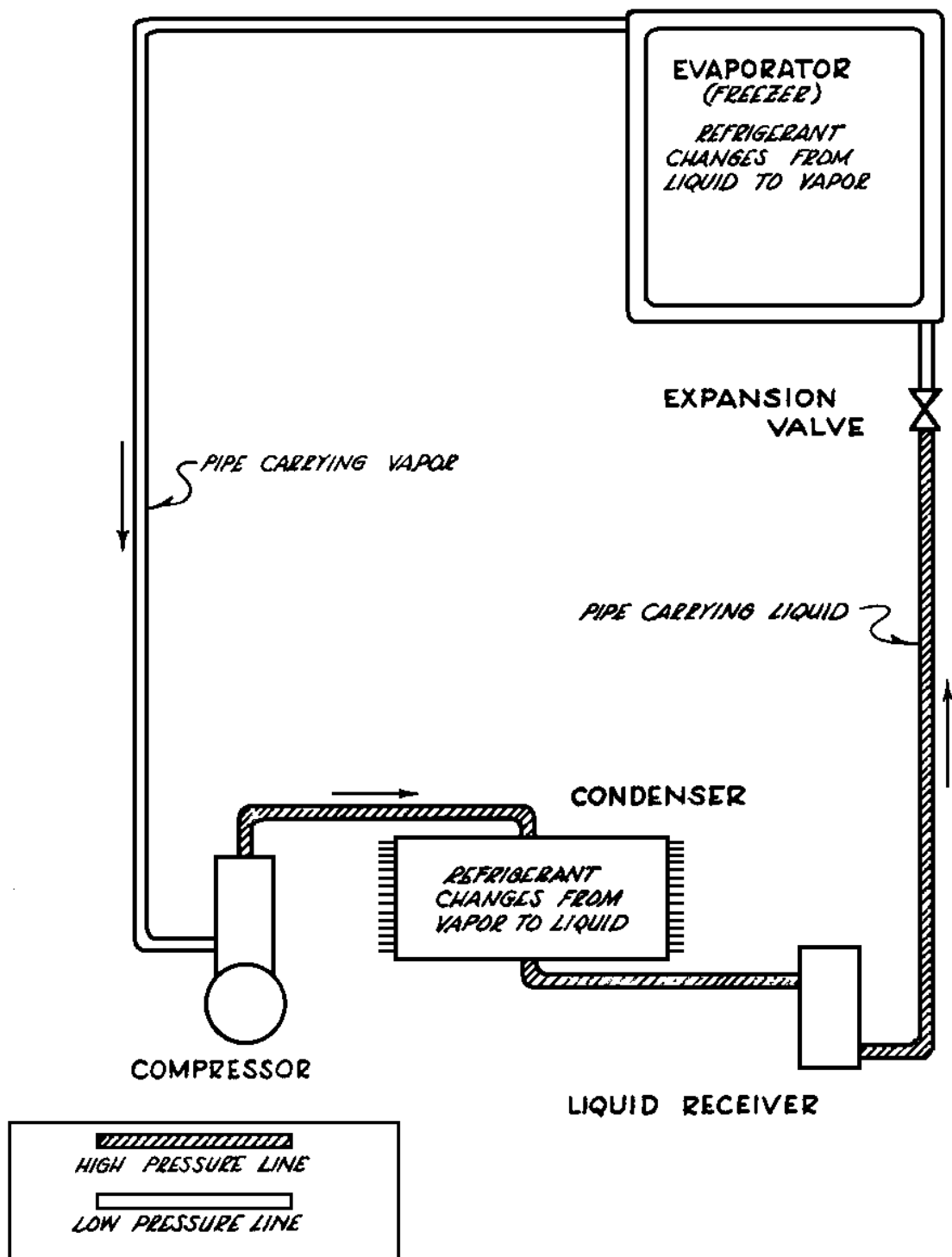


Figure 3-7. Vapor compression system.

observed, and is connected by a pipe to a purifier, which is used to remove foreign substances from the ammonia.

(5) The expansion valve is where the pressure of the refrigerant liquid is reduced so that it can begin its process of absorbing heat in the evaporator. The expansion valve will be set to release liquid at the pressure at which the refrigerant will absorb all heat units above the temperature desired in the cooling space. Adjustment of the valve by means of screw plugs, caps, or stems capable of manual manipulation permits the maintenance of a definite pressure condition in the evaporation. Any tendency toward pressure decrease would result in the valve's opening wider and permitting a greater quantity of liquid, until pressure approaches the valve setting; then the quantity admitted will decrease. The fluctuation of quantity of refrigerant admitted will vary with the refrigeration load. Since the expansion valve is a constriction, or regulating device, in the high pressure line, it allows only enough liquid refrigerant to flow through to equal that boiled off in the evaporator. Since the liquid under high pressure in the high side of the system is permitted to enter the evaporator, it is controlled either manually or by some automatic device such as an adjustable valve spring, which may be set to maintain a desired pressure in the evaporator.

3-22. THE ABSORPTION SYSTEM

a. **Principle.** Water readily absorbs ammonia gas, forming aqua ammonia. This property is fundamental in the absorption system and gives it its name. Water and ammonia vaporize at different temperatures. Consequently, if heat is applied to aqua ammonia, the ammonia gas (which boils at a low temperature) will break away from the water. When the water in the system is saturated with the gas, it is called "strong liquor". After the solution has been heated and the gas is driven off into the system, the remaining solution is called "weak liquor". The weak liquor is then carried to an absorber, where the ammonia gas, after being used in the evaporator, is returned to the water. This process creates a strong aqua ammonia or strong liquor.

b. **Apparatus.** A number of different parts are necessary for the distillation

and absorption of ammonia gas in the absorption machine because the expanded ammonia must be returned to the liquid state at high pressure for reuse. The more important parts, exclusive of various valves, gages, pipes, and fittings, are as follows (fig 3-8):

(1) **Analyzer and generator.** As the vapor rides through the analyzer, B, it passes through and over a series of baffles. There it meets and mixes with a strong ammonia solution which has been pumped into the analyzer from the exchanger, I. This strong aqua ammonia solution trickles down over the baffles in the analyzer and cools the ammonia gas ascending from the generator, A. The water vapor condenses and falls down again into the generator, while the now stronger ammonia gas passes on to the rectifier.

(2) **Rectifier.** While the generator's heating coils are evaporating the ammonia gas, which then rises through the analyzer, most of the water in the vapor will be condensed out. But in order that only dry ammonia gas will enter the condenser, the gas leaving the analyzer must pass over the cooling coils in a chamber called a rectifier, C. Here the small amount of water remaining is condensed out and the gas passes on to the condenser. The condensate flows from the separator back to the analyzer.

(3) **Condenser.** After passing from the generator through the analyzer and rectifier, the hot dry gas goes into a chamber called the condenser, D. This contains coils through which cold water is running. As hot gas strikes the cold coils, it condenses to liquid ammonia and passes from the condenser in a tank, E, called the receiver.

(4) **Receiver.** The liquid ammonia from the condenser is stored in a tank, which is usually set up at the base of the condenser so that the liquid can run from the condenser by gravity, even though the system is constantly under pressure. From the receiver, the liquid ammonia is released to the evaporator by means of an expansion valve.

(5) **Evaporator.** In all systems employing the expansion of gas as a refrigerant, the

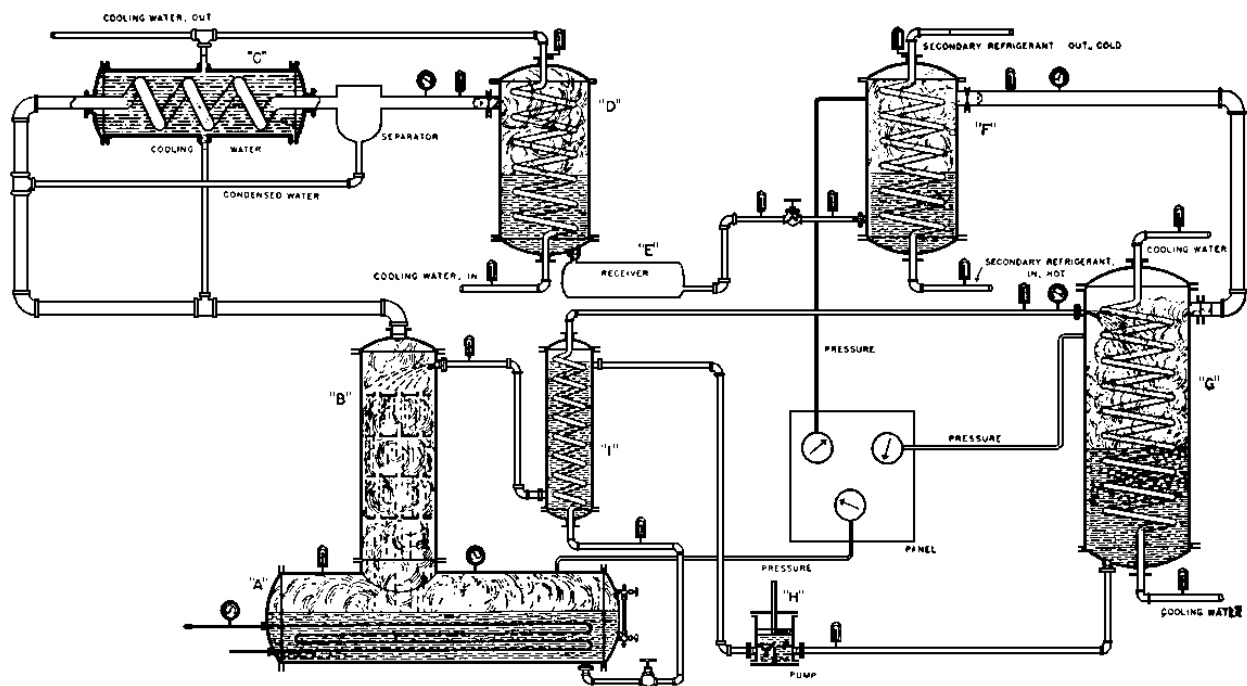


Figure 3-8. Ammonia absorption system.

evaporator, F, is the means of conveying the refrigerant to the point at which it will do its work. The evaporator also places the refrigerant in contact with a carrier of secondary refrigerant which has been piped to the area or point, and which after performing its function, returns to the evaporator to release its absorbed heat load. The absorption and vapor compression systems are alike in the principle and operation of the evaporator. As the ammonia liquid from the receiver enters the evaporator, it will absorb its latent heat of vaporization and flow on as a gas to the absorber, G, where it is brought into contact with a weak aqua ammonia solution and is absorbed, creating a strong liquor.

(6) **Absorber.** The gas flowing in from the evaporator comes in contact with a weak ammonia solution passing from the generator through the exchanger, and together they fall over cooling coils in the absorber, where the ammonia gas is absorbed by the weak solution which then becomes a strong aqua solution. This strong solution is now pumped through the exchanger, I, to the analyzer.

(7) **Exchanger.** The cool, strong aqua ammonia being pumped from the absorber is carried to a cylinder enclosing heat exchanging coils. There it is warmed before entering the analyzer and resuming its cycle. The warm or hot weak ammonia solution moves through the coils in the exchanger, passes off its heat to the strong liquid, and flows into the absorber to contact the warm strong gas from the evaporator there becoming strong liquor.

(8) **Gages.** A panel is usually installed and is provided with pressure gages to indicate the ammonia pressure in the generator, absorber and cooler. There is also a gage to show the pressure of the stem in the generator. Each gage should have a valve in the line that connects it with the apparatus. A liquid level gage should be placed on the generator, condenser, cooler, absorber, and liquid ammonia receiver.

3-23. OPERATION AND MAINTENANCE

a. General. Operation of practically all evaporator compression systems is automatic. Operation consists primarily of

inspection of the proper gages to assure efficient operation within the system.

b. Starting. It is essential that the operator know how to perform every operation which the unit is capable of performing. For starting, follow the procedures as specified in the operating instructions for the specific unit.

c. Maintenance.

(1) Maintenance as discussed herein will be considered only in the light of adding oil or refrigerant to the system. Maintenance of systems employing ammonia is similar to maintenance of most other systems. Because ammonia systems are, as a rule, larger and of more varied design, periodic routing preventive maintenance operations must be carried on. Maintenance schedules are of the greatest importance.

(2) Oil may be added to ammonia compressors of the enclosed vertical single-acting type by utilization of the suction effect of the oil pump itself. It may also be added by manipulating the valve manifold in such a way as to produce a partial vacuum within the crankcase, and then applying this vacuum to a hose or pipe that extends into the container of oil. On horizontal double-acting compressors that have forced-feed lubrication, the suction effect of the pump is utilized as described for the vertical single-acting compressor. A number of horizontal double-acting compressors use gravity oil feed, where the addition of oil involves only the simple procedure of pouring a container of oil into the oil supply tank.

(3) The addition of refrigerant liquid to an ammonia system has become a standardized operation. The liquid added is supplied directly to the liquid supply line of the system between the receiver "king valve" on top of receiver and the expansion valve. The refrigerant cylinder is tilted so that the valve outlet is down. The cylinder is rolled over until the nipple within the cylinder itself points down, thus making certain that only liquid refrigerant will come out. The plant operator must be able to determine when it is necessary to add refrigerant to the system.

He must observe carefully the suction pressure gages indicating operating conditions within the evaporator and also the height of liquid appearing in the receiver gage glass. One indication of a need for additional refrigerant is a lowering of indicated discharge or head pressure and an increase in the temperature of the liquid line at the expansion valve, which, of course, will melt frost on the expansion valve.

d. Safety precautions.

(1) Refrigerants are stored in cylinders, and in order to quickly and easily determine what refrigerant is in which cylinder, the cylinders are color coded. R-12 is in an all orange cylinder; ammonia cylinders are orange with a yellow band and brown top; R-22 has an all light green cylinder; R-113 is light green with an orange band.

(2) Extreme care should be used when working with refrigerants. Carelessness can result in serious injury and possible permanent damage to the body. First aid for exposure to refrigerants involves normal treatment for frost bite (slow warming of affected area) and application of an ointment. Medical attention should be sought immediately. If ammonia is involved first aid for a chemical burn should also be used.

(3) Guards should never be removed from the bands or pulley wheels while the machine is in motion, and should be replaced before the equipment is started. This applies even to the smallest pieces of equipment. Insulation material such as rubber mats in front of switchboards, rubber gloves for switch operators, insulated fuse pullers, etc., should

be periodically scrutinized for their serviceability. Grease spots or oil puddles should never be permitted to remain on floors. Supplies, tools, and equipment should be neatly stacked at all times, for good housekeeping helps make a plant efficient as well as safe. The correct tool for the job should always be used. For example, pipe wrenches should not be used on nuts or bolts because they produce sharp burs which may later cause a cut and an infected hand for someone else. Wrenches (particularly of the open-end type) that have split and do not fit the proper nut or bolt should be immediately discarded. Safety for personnel cannot be overemphasized.

(4) Safety of mechanical and electrical equipment is adequately provided for by the manufacturer or by installation specification requirements. These safety devices, among which are the previously mentioned pressure-relief valve, fusible plugs, overload release devices, fuses, overcurrent release, temperature release, etc., are often subjected to such mistreatment as to make them useless. A safety device that fails to function is worse than no safety device at all, because the operator, relying upon it for protection, will neglect his equipment.

e. Salt and ice mixtures. Where the temperature required is lower than that of the melting point of ice, and no power supply or equipment is available for producing refrigeration mechanically, some mixtures of salt and ice will produce temperatures as low as -30°F .

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space provided below each question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in the back of this booklet. Review the lesson as necessary. Do not send in your solutions to these review exercises.

1. Explain the difference between heat and temperature in terms of molecular motion. (Para 3-3)

2. The point at which all molecular motion ceases is called absolute zero. At what temperature does this occur? Give both the fahrenheit and centigrade temperature. (Para 3-5)
3. Convert 78° fahrenheit to degrees centigrade. (Para 3-6)
4. Convert 25° centigrade to degrees fahrenheit. (Para 3-6)
5. Name and describe briefly the three methods by which heat is transferred. (Para 3-8)
6. Define sensible heat. (Para 3-9)
7. Define latent heat. (Para 3-10)
8. It takes one British thermal unit (Btu) to raise the temperature of one pound of water one degree Fahrenheit, (sensible heat). How many Btu's are required to turn water to steam with no increase in temperature, (latent heat)? (Para 3-11)
9. What effect does a lowering of pressure on a liquid have upon the boiling point of that liquid? (Para 3-13e)
10. What are the two condition changes that will cause a vapor to condense? (Para 3-14)

11. Define a "Ton" of refrigeration. (Para 3-16)
12. State briefly the principles upon which mechanical refrigeration is based. (Para 3-18b)
13. Upon which of the undesirable characteristics of refrigerants has the National Board of Fire Underwriters based their refrigerant classification system? (Para 3-18d)
14. How does the maintenance man usually determine whether or not the refrigeration system is fully charged? (Para 3-18g)
15. In ice plants where ammonia is the refrigerant used, what is the normal method used to detect a refrigerant leak? (Para 3-19b(3))
16. Describe what happens to ammonia in an open container as its temperature rises above -28° F. (Para 3-20b)
17. What is the boiling point of ammonia if it is in a closed container and the pressure reaches 16 pounds gage? (Para 3-20c)
18. What are the four essential or, basic parts of the vapor compression system? (Para 3-21a)
19. What is the basic principle upon which the absorption system of refrigeration is based? (Para, 3-22a)

20. If the expansion valve in a vapor-compression refrigeration system becomes clear of frost during operation, what conclusion can be drawn? (Para 3-23c(3))

LESSON 4

WATER SUPPLY AND DISTRIBUTION SYSTEMS

CREDIT HOURS 2

TEXT ASSIGNMENT Attached memorandum.

MATERIALS REQUIRED None.

LESSON OBJECTIVE Upon completion of this lesson on water supply you should be able to accomplish the following in the indicated topic areas.

1. **Corps of Engineers responsibilities.** Define the Corps of Engineers involvement in the supply of water and the various levels of responsibility.

2. **Definitions and formulas.** State the common terms used in water supply along with their definitions. Give the formulas and factors used in determining flow, pressure, head, and head loss.

3. **Distribution systems.** Describe the three basic types of distribution systems to include open channels, pipes, storage facilities, treatment, and distribution.

4. **Water requirements.** Determine water requirements for the various types of installations and activities.

5. **Pipeline design.** Explain the sequence and considerations in pipeline design to include reconnaissance, surveys, layout, availability, and simple and compound systems.

6. **Operation and maintenance of systems.** State the essential points in operation and maintenance of water supply and distribution systems.

ATTACHED MEMORANDUM

4-1. INTRODUCTION

An adequate supply of palatable, safe water is an essential prerequisite for the health, general welfare, combat efficiency, and morale of troops. The supplying of this water is one of the primary functions of the Corps of Engineers. Hence, this lesson is for the engineer officer confronted with the task of providing potable water for small and medium semi-permanent military installations. It contains minimum information required for designing a stationary system to provide safe water.

4-2. PLANNING, DESIGN, AND CONSTRUCTION

a. **Phases.** The work of planning, designing, and constructing utilities is divided into the following phases:

- (1) Preliminary investigation.
- (2) Engineering layout and design.
- (3) Scheduling construction.
- (4) Supervising construction.

b. **Planning guides.** Planning of utilities for a project is based on Department of the

Army general policy and is guided by the theater construction policy and the job directive.

(1) Theater construction policy is issued by headquarters to establish uniform construction practice and to conserve labor, equipment, and materials. The policy sets maximum standards for initial, temporary, and semi-permanent construction, and recommends typical designs.

(2) Job directives are issued by higher headquarters to initiate the project and define the construction by establishing the following:

(a) Location of construction site by limiting coordinates with reference to a known point, aerial photograph, or map.

(b) Enumeration of major facilities and basic requirements.

(c) Priorities of construction for the various facilities.

(d) Required dates of usable completion.

c. Responsibilities of the officer in charge. To carry out the various phases of work successfully, the officer in charge of installing utilities for a camp, hospital, or other installation must plan and perform the following tasks in their proper sequence.

(1) Site reconnaissance. A personal reconnaissance of the site is made to obtain information on its physical characteristics and other factors affecting the proposed construction.

(2) Preliminary field investigation. Plane and topographic surveys, soil borings, stream-flow measurements, and the like are made for engineer planning and designs as required.

(3) Inventory of available resources. The officer in charge inventories the materials, labor, equipment, and other available construction facilities and takes steps to secure all items required for the completion of the project on schedule.

(4) Engineering designs. Layouts and designs are prepared and used as a basis for constructing all utilities installations.

(5) Quantity survey. The lists of materials that must be ordered or

requisitioned and the estimates of the principal items of work, such as excavations to be made or concrete to be placed, are taken from the engineering plans and work sheets.

(6) Priorities and stages of construction. Priorities establish the order in which construction of the various individual utilities must be completed. Stage construction, the procedure followed when a project is completed either by units or by levels of improvement, permits early use of items of high priority, such as water and electricity.

(7) Forecast of working conditions. Working conditions, including climatic conditions, interference due to use of the project before completion, and effects of enemy action are estimated before construction begins.

(8) Schedule of operations. Construction operations are scheduled to show the sequence of operations and the time allotted for each work item. Sequence is the order in which operations must begin. Work items are specific tasks for which the work output of men and equipment is known or can be estimated.

(9) Supervision of construction. Supervision of construction requires the control, coordination, and adjustment of construction schedules and operations to insure that the work is done according to plans in an efficient, expeditious, and safe way.

(10) Accident prevention. All hazards to safety observed during preliminary investigations, construction, and operation of utilities should be eliminated or a positive control provided.

(11) Maps. As construction progresses, maps showing the location of all utilities and their important component parts are prepared for use in future operations and repairs.

4-3. COMMONLY USED TERMS IN WATER SUPPLY AND DISTRIBUTION

a. Discharge. The rate of flow or volume of water passing a given point in a conduit or

channel in a given time is discharge (Q). It is usually measured in cubic feet per second (cfs), gallons per minute (gpm), or gallons per day (gpd). Discharge is expressed by the basic formula: $Q = AV$

Where: Q = discharge in cfs.

A = cross-sectional area of conduit or channel in square feet,

V = average velocity in feet per second (fps).

b. Atmospheric pressure.

Atmospheric pressure varies slightly from time to time depending on weather. It also varies with elevation above or below sea level. Except in computations requiring extreme accuracy it is assumed to be 14.7 pounds per square inch (psi).

c. Pressure. Pressure is force exerted on an area. It may be expressed in various units, such as pounds per square inch, pounds per square foot, or grams per square centimeter. A column of water 1 foot high exerts a pressure of 0.433 pound per square inch (psi) regardless of the diameter of the column.

d. Relationship of pressure and head. Pressures are expressed in pounds per square inch (psi) or in feet of water depth. The depth of water required to produce a given pressure is termed head.

Example:

62.4 pounds per cu ft (weight of water)

144 sq in. (1 sq ft)

= 0.433 psi per ft of height or head.

144 sq in. (1 sq ft)

62.4 pounds per cu ft

= 2.31 ft of height or head per psi.
In other words; a column of water 2.31 feet high exerts a pressure of 1 psi on its base. Conversely, 1 psi exerted on the base of a column of water will raise it 2.31 feet. Thus, to convert pressure in psi to head in feet, multiply by 2.31; and to convert head in feet to psi, multiply by 0.433.

e. Difference in pressure. If the tank in figure 4-1 is full of water, the head of water at point A is 5 ft. The pressure exerted is 5×0.433 , or 2.165 psi. Points B, C, and, D are calculated in the same way. The difference between unit pressures at any two points in a liquid at rest is found by first computing the unit pressure at each point and then subtracting one value from the other. For example, if one point is at a depth of 20 feet below the surface, the surface of a body of water and the other point is at a depth of 30 feet below the surface, the intensities of pressures at the points are 8.36 psi (20×0.433) and 12.99 (30×0.433), respectively. The difference in pressure between the two points is 4.33 psi. This same relationship applies to other liquid under pressure, whether it has a free surface or not, primarily because the intensity of pressure at every point on the surface of the liquid is the same. In other words all points in the same plane perpendicular to the vertical line of gravity have the same pressure exerted on them whether the overlying liquid is under pressure or not.

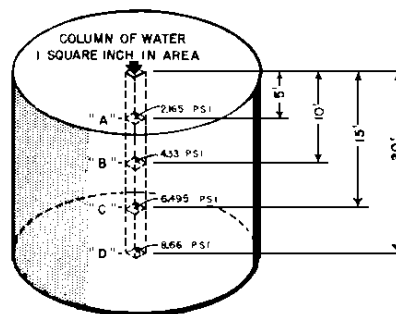


Figure 4-1. Pressure and pressure head.

f. Absolute and gage pressures.

Pressure intensities may be expressed with reference to either of two bases; absolute zero pressure such as exists in a complete vacuum; or atmospheric pressure, which at sea level averages 14.7 pounds per square inch (psi) above absolute zero pressures. Absolute pressures are used primarily with steam and are always positive. In water supply and distribution, however, it is more convenient to use atmospheric pressure as the base or

zero pressure. Pressures which use atmospheric pressure as the reference point are called gage pressures. Gage pressures above atmospheric pressure are positive; those below atmospheric pressure are negative and are written with a minus (--) sign. Accordingly, for example, 5 psi gage pressure is taken to equal 5.0 + 14.7, or 19.7 psi absolute pressure. Conversely, a gage pressure of -5 psi is equal to 14.7 -- 5.0, or 9.7 psi absolute pressure.

g. Relationship of gage and absolute pressures. The theoretical relationship between absolute pressure and gage pressure is illustrated in figure 4-2 which represents a water barometer. If it is assumed that the space above the water in the tube consists of an absolute vacuum, with no pressure from vapor, the surface x-x of the water in the tube will be 33.9 feet above the free surface d-d, which is exposed to atmospheric pressure. If a certain section y-y is 14.0 feet below x-x and 19.9 feet above d-d, for example, the absolute pressure is equal to the weight of the overlying water, which is 14.0 feet. The gage pressure at the line y-y is negative, however, because this section is above the level d-d at which there is full atmospheric pressure. The amount of this negative pressure is equal to the height of the section y-y above the free surface d-d, or 19.9 feet. Therefore, the gage pressure is equal to the negative head of the volume of water, or

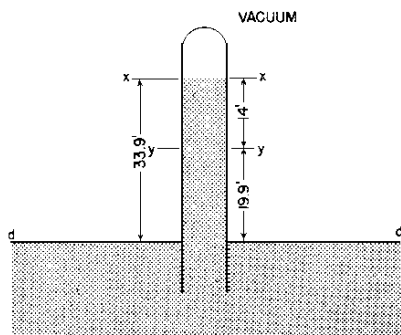


Figure 4-2. Water barometer.

-19.9 feet. As indicated in c above-- 19.9 times 0.433 equals -8.6 psi.

h. Head losses. To start and maintain a flow of water in either open channels or pipes, energy is required, the amount of which is measured and expressed by loss of head. These losses are termed **velocity-head** and **friction-head** losses.

(1) Velocity-head loss is equal to the energy required to overcome inertia in starting the flow or increasing its velocity. In a gravity system this loss is evaluated by the formula:

$$h = \frac{V_2^2 - V_1^2}{2g}, \text{ in which}$$

V_1 = initial velocity in feet per second
 V_2 = final velocity in feet per second
 g = acceleration of gravity = 32.2 feet per second per second
 h = head

Example: A stream of water is flowing through a channel, whose cross section is a semicircle, at a velocity, V , of 15 feet per second. The head required to overcome the inertia and increase the velocity to 30 feet per second, assuming no loss due to friction, would be:

$$h = \frac{V_2^2 - V_1^2}{2g} = \frac{30^2 - 15^2}{2(32.2)} = \frac{675}{64.4} = 10.5 \text{ feet}$$

(2) Friction-head loss is equal to the energy required to overcome the friction between the surface of the channel of pipe and the moving water. Many formulas have been designed to determine the friction loss. The most common formula used in American practice for calculating friction-head loss in pipes is the Hazen-Williams formula:

$V = 1.318 C R^{0.63} S^{0.54}$, in which
 V = velocity of water in ft per second
 C = coefficient of friction (120 is recommended for clean new pipe; 60 for old tuberculated pipe; 100 is recommended for design),

S = loss of head per foot of pipe,
 R = hydraulic radius (by definition, the hydraulic radius is the cross-sectional area divided by the wetted perimeter or one-half the inside radius of a completely filled pipe of circular cross section).

Example: Find the head required to overcome the friction per foot of pipe if the water is flowing at a velocity of 25 feet per second through a pipe whose inside diameter is 2 feet and coefficient of friction is 100.

$$V = 1.318 CR^{0.63} S^{0.54}$$

$$S = \frac{V^{1.85}}{C^{1.85} R^{1.17}} \times \frac{1}{1.318^{1.85}}$$

$$\log S = 1.85 \log V - 1.85 \log C - 1.17 \log R - 1.85 \log 1.318$$

$$\log S = 1.85 \log 25 - 1.85 \log 100 - 1.17 \log 1.318$$

$$\log S = 1.85 (1.398) - 1.85 (2) - 1.17 (-1.699) - 1.85 (0.12)$$

$$\log S = 2.58 - 3.7 - 1.17 (9.699 - 10) - 1.85 (0.12)$$

$$\log S = 2.58 - 3.7 - 11.35 + 11.7 - 0.22$$

$$\log S = 14.28 - 15.27 = -0.99$$

$$\log S = 1 \log .99$$

$$\log S = \frac{1}{.99} = 0.10 \text{ ft head loss per ft of pipe}$$

(3) When water is received from a source which is higher than the point of distribution, the available head created by a difference in height may be used to overcome friction in pipe and also maintain a given head at the point of distribution. For example, if a source of water was located 18 feet above the point of distribution and if the head required to provide adequate pressure at this point was 5 feet, 13 feet of head is available to take up the friction-head loss. Friction-head loss as calculated by the Hazen-Williams formula is expressed in feet of water. The head

loss may always be overcome by raising the water source an amount equal to the height of the loss in feet of head in the pipe.

(4) Figure 4-3 is a chart from which you may read directly the friction-head loss per 1,000 feet of various size pipe (using C = 100), when you know either the quantity of flow in gallons per minute (gpm) or the velocity of flow in feet per second (fps). For example, for a flow of 300 gallons per minute in a 4-inch pipe, with C = 100, the friction head is 80 feet per 1,000 ft of pipe. This is determined by finding the 300-gpm line on the vertical scale, following this line across horizontally to its intersection with the diagonal line representing 4-inch pipe. The friction-head loss, 80 feet, may be read on the horizontal scale directly below the point of intersection. If the velocity and pipe size are known, the head loss in feet can be read on the horizontal scale directly below the point of intersection of the velocity lines and pipe-size lines. For example, a velocity of 7.1 fps in a 4-inch pipe, with C = 100, would produce a friction-head loss of 80 feet in 1,000 feet of pipe. Intermediate values and measurements not actually shown by lines on the chart are determined by interpolation.

(5) Other head losses are caused by changes in pipe sizes and by pipe fittings, such as bends, tees, and crosses. Such losses are included in all calculations by substituting the length of straight pipe which would produce an equivalent amount of head loss (fig 4-4).

i. **Static head** is the pressure occurring when all valves are closed and the water is not flowing. The amount of pressure during flow is obtained by subtracting velocity, friction, and other head losses from the static head.

j. **Suction head** is the term used to indicate negative gage pressures. It is measured at the inlet flange of pumps set above the elevation of the reservoir, lake, or stream from which

water is drawn. Flow to the pump in

such cases is caused only by the

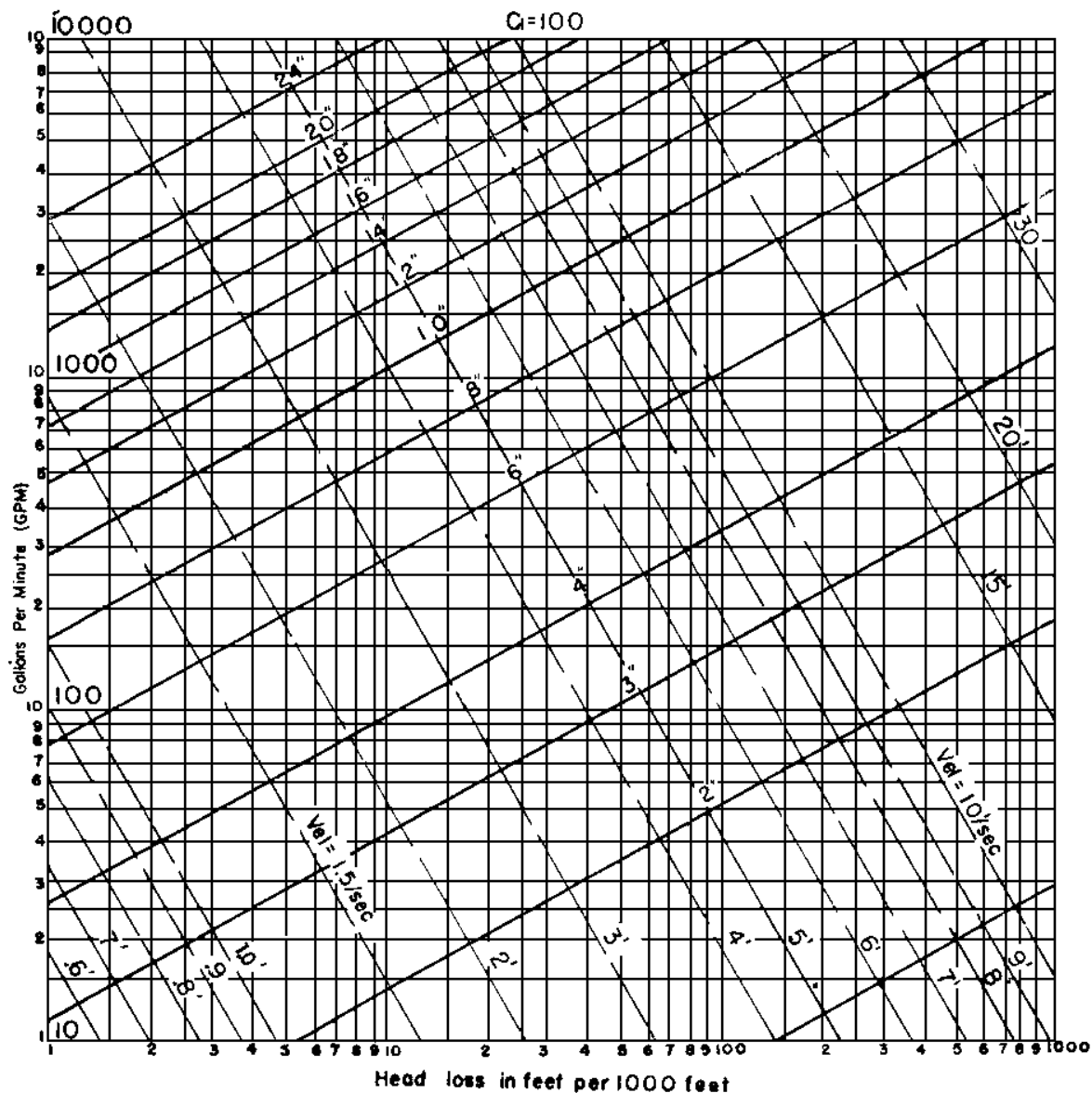


Figure 4-3. Friction loss in pipes (Hazen-Williams formula).

atmospheric pressure on the reservoir surface. You have learned that atmospheric pressure is 14.7 psi and that this is equivalent to a head of 33.9 feet (14.7×2.31). Theoretically, water can be "sucked up" (in reality, pushed up) 33.9 feet to the pump, but because of velocity, friction, and other losses in the pump and intake pipe, satisfactory operation cannot be maintained in excess of about 20 feet.

k. Suction lift is the vertical distance in feet from the level of the water source to the pump (fig 4-5).

l. Velocity is the speed of flow of water, usually expressed in fps.

m. Quantity is the amount of flow of water expressed in cubic feet per second (cfs) or in gpm.

EXAMPLE: DOTTED LINE SHOWS THAT RESISTANCE OF A 6" STANDARD SHORT RADIUS ELBOW IS EQUIVALENT TO 16' OF 6" STANDARD PIPE.

NOTE: FOR SUDDEN ENLARGEMENTS OR CONTRACTIONS, USE THE SMALLER DIAMETER, d , ON PIPE SIZE SCALE.

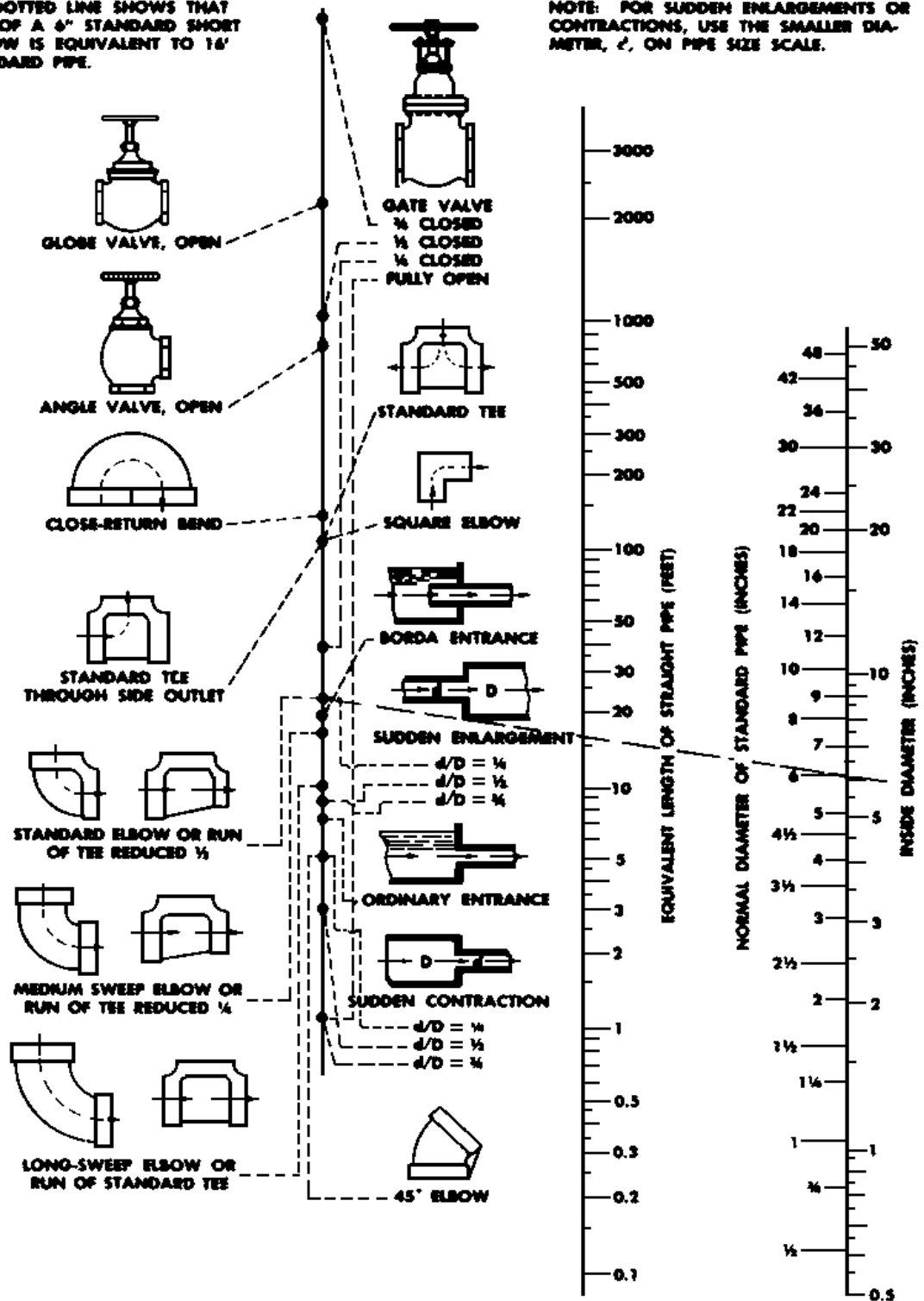


Figure 4-4. Friction effects of fittings and of changes in pipe sizes.

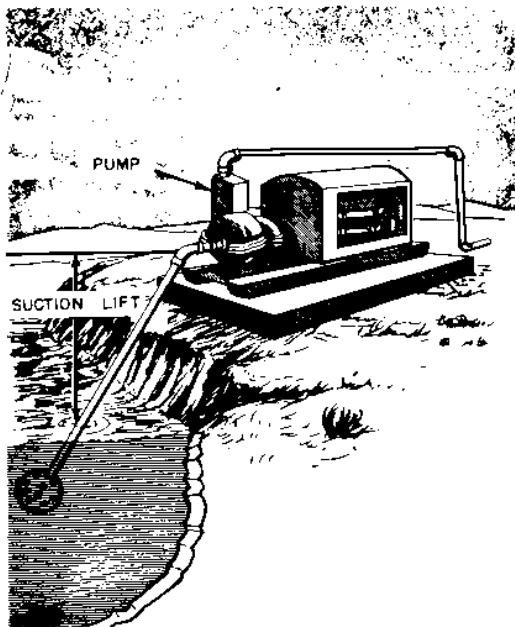


Figure 4-5. Suction-lift pump.

4-4. OPEN CHANNELS

a. Surface-velocity method. To determine discharge in open channels by the surface-velocity method, proceed as follows:

(1) Find the cross-sectional area of the stream in square feet by multiplying the average stream depth by the width.

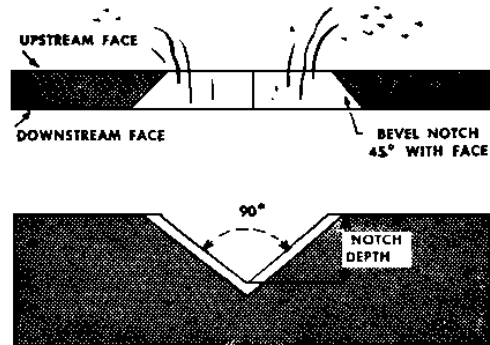
(2) Find the average velocity of the stream. To do this, observe the time required for a floating object to travel a given distance, and compute the surface velocity in fps. Assume the average velocity is three-quarters of the surface velocity.

(3) Compute the discharge (Q) using the discharge formula, $Q = AV$.

b. Weir method. The 90-degree V-notch sharp-edge weir is a convenient and accurate way to measure flows from 5,000 to 9,000,000 gpd. Weirs are easily improvised in the field and readily transported to the point of use.

(1) **Construction.** Construction details for the 90-degree V-notch sharp-edge weir are shown in figure 4-6.

(2) **Installation.** Install the weir as part of a dam so the water backs up at least



WEIR MAY BE MADE OF SHEET METAL OR 1" BOARD

6" NOTCH DEPTH MEASURES
DISCHARGES UP TO ¼ MILLION GPD

12" NOTCH DEPTH MEASURES
DISCHARGES UP TO 1½ MILLION GPD

24" NOTCH DEPTH MEASURES
DISCHARGES UP TO 9 MILLION GPD

Figure 4-6. Construction details of 90°, V-notch sharp-edge weir.

two and one-half times deeper than the expected head on the weir (fig 4-7). The top edge of the weir should be approximately level.

(3) **Head measurement.**

(a) Measure the distance from top of weir to water surface on the upstream face at two points, each point about 1« feet from the weir notch (fig 4-8).

(b) Average these two measurements.

(c) Subtract the average of the two measurements from the notch depth. This gives the head on the weir.

(4) **Discharge.** From the head on the weir, determine the discharge (table 4-1).

c. Manning's formula method.

(1) The discharge of an open channel may be determined by computation using Manning's formula.

$$V = \frac{1.486 r^{2/3} \sqrt{s}}{n}$$

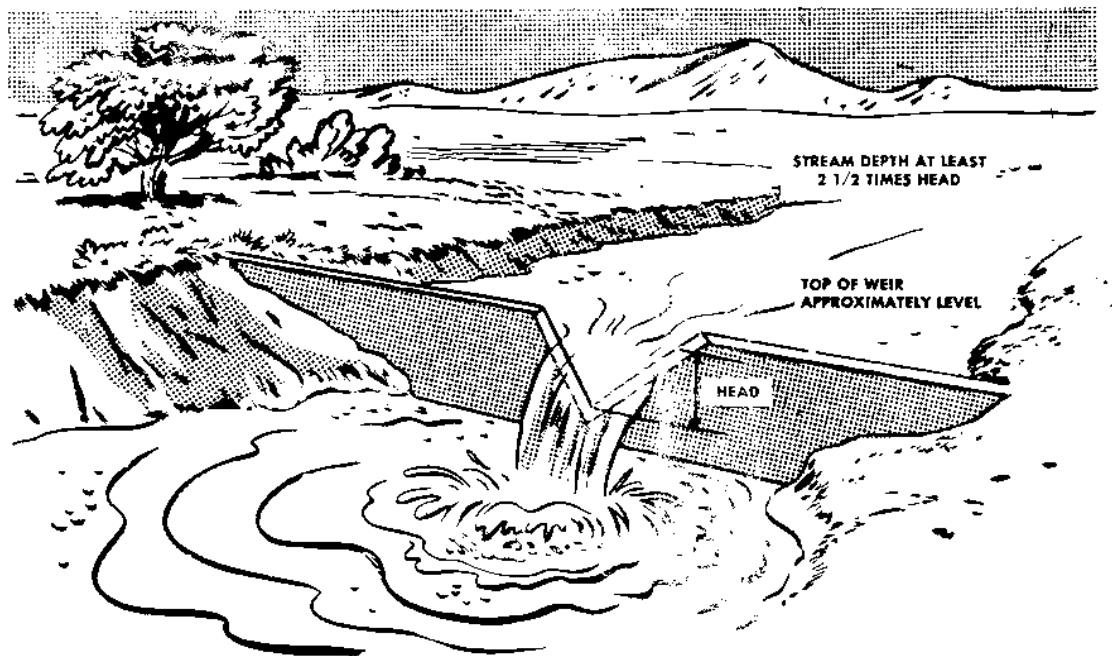


Figure 4-7. Weir installation.

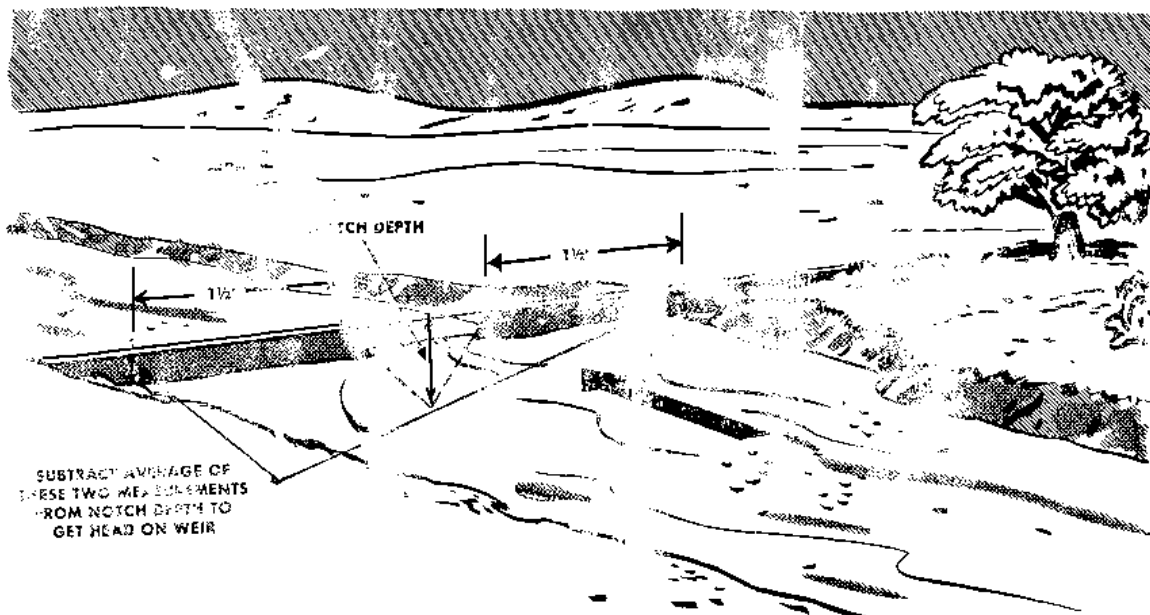


Figure 4-8. Measuring head on a weir.

Where: V = average velocity in fps.
r = hydraulic radius (the cross sectional area in square feet divided by the wetted perimeter in feet).
s = slope of channel in feet per foot of channel length.
n = coefficient of roughness which varies for different channel surfaces as follows:
n = .012 for smooth planed timber or smooth cement mortar.
n = .013 for smooth brickwork, smooth concrete, or vitrified tile.
n = .014 for average concrete.
n = .015 for rough brickwork.
n = .020 for rubble masonry or canals in firm ground.
n = .025 for canals or rivers with sides in good condition.
n = .030 for canals or rivers with some stones or weeds.
n = 0.50 for rivers with channels obstructed by stones and weeds.

(2) After finding the average velocity by Manning's formula, compute the discharge (Q) from the discharge formula, $Q = AV$.

4-5. PIPES

a. General. Flow of water in a given length of pipe depends on pipe size, a friction factor C indicative of the interior roughness of the pipe, and the difference in pressure head (head loss) between the two ends of the pipe.

b. Finding discharge.

(1) Discharge may be found from the nomograph shown in figure 4-9. To determine

TABLE 4-1. Discharge for 90-degree, V-Notch, Sharp-Edge Weir

Head (in.)	Discharge (cfs)	Head (in.)	Discharge (cfs)
1	.0053	10	1.607
$\frac{1}{8}$	.0073	$\frac{1}{8}$	1.812
$\frac{1}{4}$	.0094	11	2.031
$\frac{3}{8}$	.0120	$\frac{1}{4}$	2.260
$\frac{1}{2}$	.0148	12	2.520
$\frac{5}{8}$	.0181	$\frac{3}{8}$	2.787
$\frac{3}{4}$	.0217	13	3.072
$\frac{7}{8}$	.0257	$\frac{1}{2}$	3.371
2	.0301	14	3.687
$\frac{1}{8}$	.0403	$\frac{1}{2}$	4.022
$\frac{1}{4}$	.0524	15	4.373
$\frac{3}{8}$	.0663	$\frac{3}{8}$	4.742
3	.0821	16	5.129
$\frac{1}{4}$	.1000	$\frac{1}{2}$	5.534
$\frac{1}{2}$	.1202	17	5.958
$\frac{3}{4}$	.142	$\frac{1}{4}$	6.399
4	.167	18	6.860
$\frac{1}{4}$	.194	$\frac{1}{4}$	7.342
$\frac{1}{2}$	.224	19	7.839
$\frac{3}{4}$	.256	$\frac{1}{2}$	8.36
5	.291	20	8.90
$\frac{1}{2}$	.366	$\frac{1}{4}$	9.45
6	.455	21	10.04
$\frac{1}{2}$	.555	$\frac{1}{2}$	10.64
7	.666	22	11.28
$\frac{1}{2}$	.789	$\frac{1}{4}$	11.90
8	.926	23	12.57
$\frac{1}{2}$	1.075	$\frac{1}{2}$	13.25
9	1.238	24	13.96
$\frac{1}{2}$	1.415		

Notes. To convert discharge to gpm, multiply above values by 449.
To convert discharge to gpd, multiply above values by 647,000.
Discharges computed from formula $Q = 2.52 H^{3/2}$
Where: Q = discharge in cfs
H = head in feet.

discharge using the figure, the pipe size, condition of pipe interior, and the loss of head in feet per 1,000 feet of pipe must be known. Loss of head in feet per 1,000 feet of pipe is found by dividing the difference in pressure head in feet at the two ends of the pipe by the apparent pipe length in thousands of feet. Difference in pressure head is caused by difference in elevation or by a pump. For pipe without obstructions such as valves, bends, fittings, and enlargements or contractions, the apparent length equals the measured length. For pipe with obstructions, the apparent length equals the measured length plus the equivalent length of each obstruction (Tables 4-2 and 4-3).

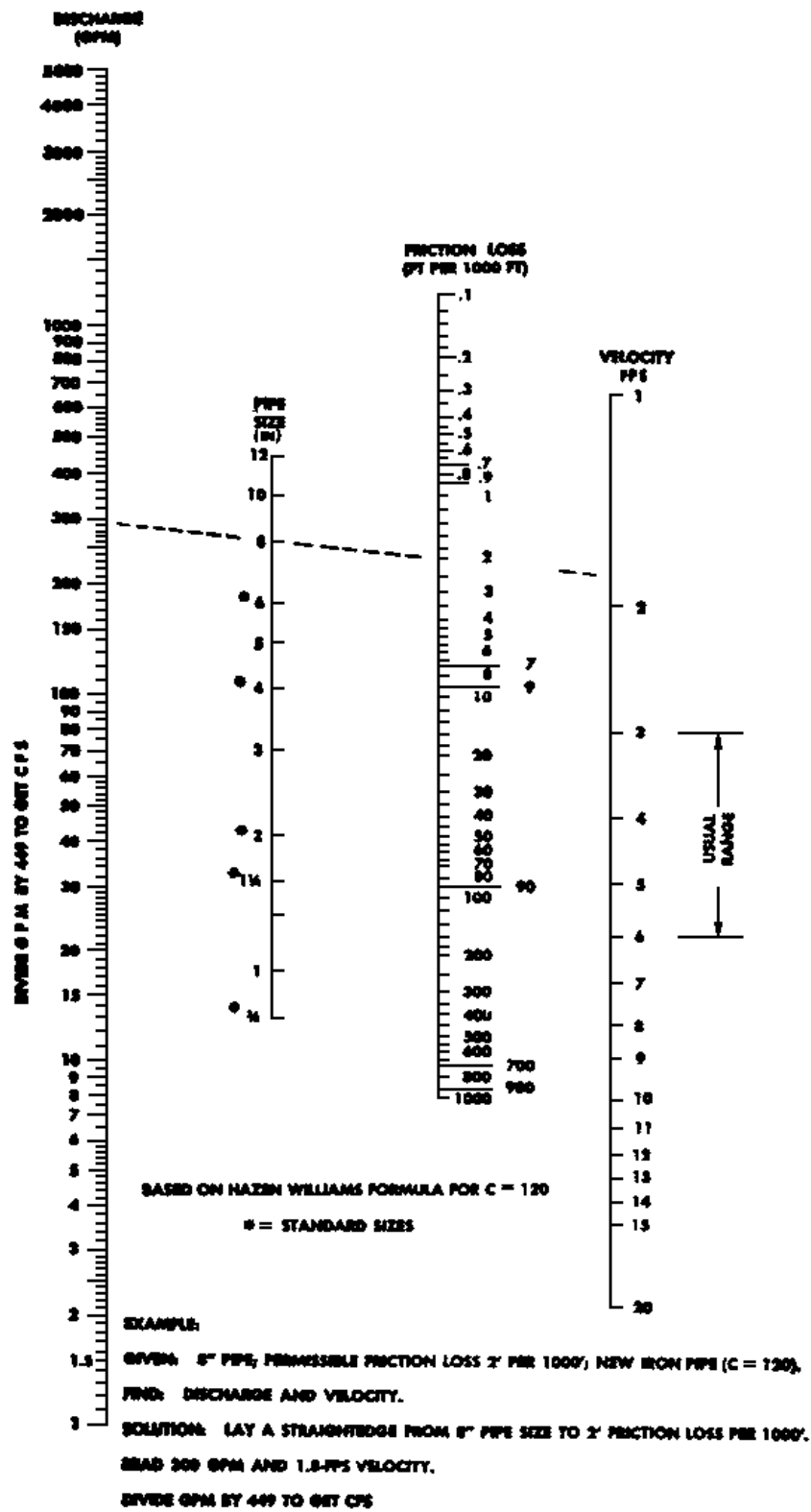


Figure 4-9. Nomograph for solving pipe-flow problems.

TABLE 4-2. Head Loss Due to Enlargements and Contractions in Pipes



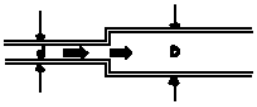
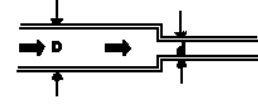









	Ordinary entrance	Rounded entrance	Sudden enlargement			Sudden contraction		
			$\frac{d}{D} = \frac{1}{4}$	$\frac{d}{D} = \frac{1}{2}$	$\frac{d}{D} = \frac{3}{4}$	$\frac{d}{D} = \frac{1}{4}$	$\frac{d}{D} = \frac{1}{2}$	$\frac{d}{D} = \frac{3}{4}$
Size of pipe d								
Length of straight pipe d giving equivalent resistance to flow								
1/2"	.9	1.3	1.5	1.1	1.0	.77	.39	.38
3/4"	1.2	2.	2.2	1.4	1.3	1.0	.79	.47
1"	1.5	2.3	2.7	1.7	1.6	1.3	.99	.6
1 1/4"	2.	3.3	3.7	2.4	2.2	1.6	1.3	.8
1 1/2"	2.4	4.0	4.3	2.8	2.6	2.0	1.5	.96
2"	3.	5.	5.3	3.3	3.2	2.3	1.9	1.2
2 1/2"	3.6	6.	6.5	4.2	3.9	3.0	2.3	1.4
3"	4.3	7.6	8.1	5.1	4.9	3.5	2.8	1.7
3 1/2"	5.1	9.	9.3	6.0	5.6	4.4	3.3	2.
4"	6.		11.	7.0	6.5	5.0	3.8	2.3
4 1/2"	6.6	12	12.	7.9	7.1	5.3	4.3	2.6
5"	7.3	13.	14.	8.9	8.1	6.1	4.8	2.9
6"	9.	15.	16.	11.	10.	7.7	5.7	3.3
8"	12.	20.	21.	14.	13.	10.	7.6	4.3
10"	15.	25.	26.	17.	16.	13.	9.7	5.7
12"	18.	30.	32.	20.	19.	15.	11.	6.7

TABLE 4-3. Head Loss Due to Valves and Fittings

	Standard elbow	Medium-radius elbow	Long-radius elbow	45° elbow	Tee	Return Bend	Gate valve open	Globe valve open	Angle valve open
Size of pipe nominal dia.									
Length of straight pipe giving equivalent resistance to flow									
1/2"	1.5	1.4	1.1	.77	3.4	3.8	.35	16	8.4
3/4"	2.2	1.3	1.4	1.0	4.5	5.0	.47	22	12.
1"	2.7	2.3	1.7	1.3	5.8	6.1	.6	27	15.
1 1/4"	3.7	3.0	2.4	1.6	7.3	8.5	.8	37	18.
1 1/2"	4.3	3.6	2.8	2.0	9.0	10.	.95	44	22.
2"	5.5	4.6	3.5	2.5	11	13.	1.2	57	28.
2 1/2"	6.5	5.4	4.2	3.0	14	15.	1.4	66	33.
3"	8.1	6.8	5.1	3.6	17	18.	1.7	85	42.
3 1/2"	9.3	8.0	6.0	4.4	19	21.	2.	99	50.
4"	11.	9.1	7.0	5.0	22	24.	2.3	110	58.
4 1/2"	12.	10.	7.9	5.6	24	27.	2.6	130	61.
5"	14.	12.	8.9	6.1	27	31.	2.9	140	70.
6"	16.	14.	11.	7.7	33	37.	3.5	160	83.
8"	21.	18.	14.	10.	43	49.	4.5	230	110.
10"	26.	22.	17.	13.	56	61.	5.7	290	140.
12"	32.	26.	20.	15.	66	73.	6.7	340	170.

(2) Normally, the effect of obstructions is small and may be disregarded, the apparent length being taken as the measured length. However, in short systems having many obstructions, the effect of obstructions should be included in the apparent length.

4-6. SUPPLY LINES AND DISTRIBUTION SYSTEMS

a. Function. Supply lines carry water from the gravity intake, pumping station, treatment plant, reservoir, or storage tank to the distribution system which conveys it to the outlet.

(1) An ample supply of safe water for drinking, cooking, and bathing is essential for every Army installation. It is desirable that the water be clean, colorless, and odorless, and that the system be capable of delivering it without interruption. No water from natural sources is chemically pure, but safe water has only limited amounts of harmful chemicals and no pathogenic bacteria. A water-supply system includes a source, intakes, conveyances, facilities for storage and/or treatment, and a distribution system consisting of mains, submains, valves, branch lines, and service lines (see fig 4-10).

(2) Sources of water include natural or impounding reservoirs, streams, wells, catch basins for rain, and bodies of salt water.

(3) Intakes are used as a means of obtaining water from its source. This may be done by pump, gravity flow, or by a combination of pump and gravity flow. Screens are used on intakes at surface sources to keep fish and floating debris out of the water system. In wells they are used to keep out sand.

(4) If the source is distant from the point of consumption, aqueducts, pipelines, or open channels are needed to convey the water. In rare instances mobile water-transport units must be used.

(5) In all military and most civilian systems, a treatment plant is required. Normally, chlorine is used in these plants as the disinfecting

agent, but, in some cases, oxygen or iodine may be used.

b. Description.

(1) **Basic systems.** There are three basic types of water supply and distribution systems.

(a) Gravity. Storage reservoirs of gravity distribution systems are usually located high enough to develop required pressure and flow. Storage tanks may sometimes be gravity filled from springs located at a higher elevation than the water level of the tanks, but are usually filled with pumps. Because of their relative elevation, the storage tanks eliminate need for continuous pumping.

(b) Direct pumping. Direct pumping systems usually have no elevated storage tanks and water must be pumped into the distribution system from ground storage reservoirs, wells, or the distribution system of a municipality or other source, at a rate depending on demand. Therefore, continuous pump operation is necessary.

(c) Combination of gravity and pumping. A combination system can be used, with the primary mains being supplied from the two sources mentioned above.

(2) Pipes.

(a) Classification. The network of pipes should be arranged so large primary mains feed smaller secondary pipes. Service pipes carry water from the main to the buildings. Mains carry water from the source to the service pipes.

(b) Arrangement. Distribution systems may be arranged as a dead-end system or as a loop system. In dead-end systems, the flow is not continuous. In loop systems, the ends of all mains are connected so water circulates continuously, while it is being drawn from any point on the loop.

c. Design. The design of a distribution system is based on the known requirements and on the physical data obtained from reconnaissance, surveys, and maps.

4-7. REQUIREMENTS

a. Demand. The distribution system should deliver enough water to meet the

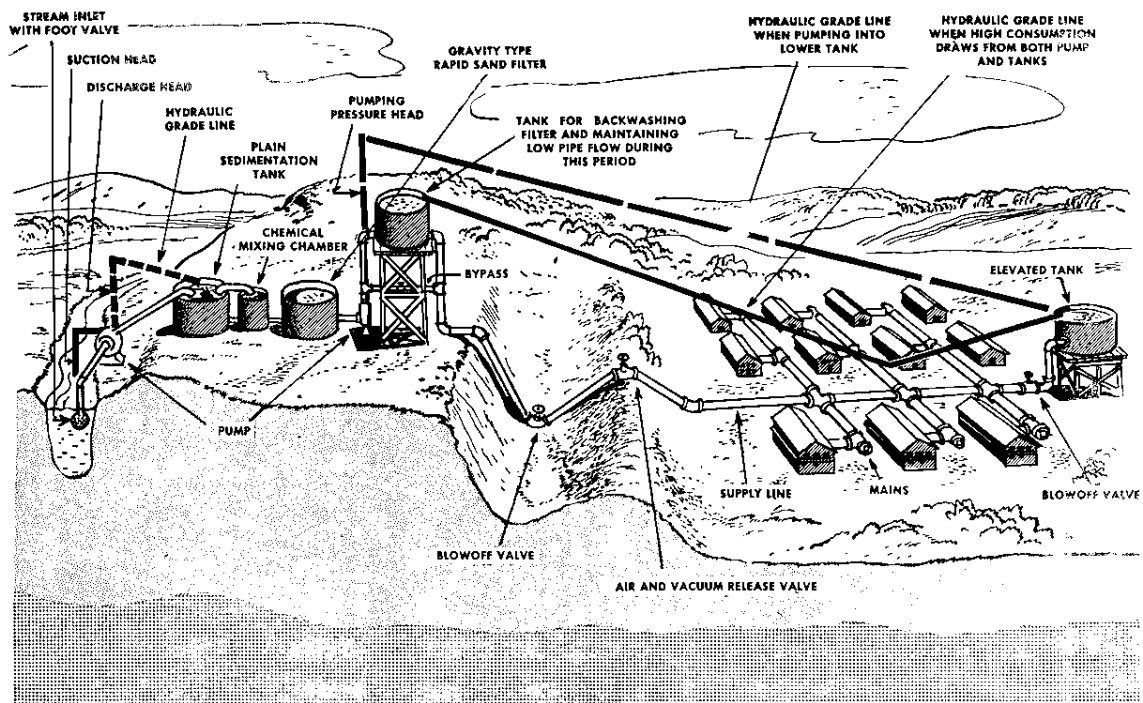


Figure 4-10. Diagram of pumping station.

maximum rate of demand (peak demand) for drinking, cooking, personal hygiene, and other authorized uses.

(1) **Peak demand.** The size of the distribution main serving an area depends on the total peak water demand for that area. Service connections and mains must be large enough to deliver the total peak demand under the available pressure. The factors for determining peak demand, in gpm, for any area serviced by a single main are given in table 4-4.

(2) **Fire protection.** Normally, distribution systems are not constructed large enough to supply the large demand required for fire protection. It is best to provide ground storage tanks or sumps at strategic points so all buildings can be reached with not over 1,000 feet of hose. Water is pumped

TABLE 4-4. Factors for Determining Peak Water Demands

Number of outlets	Peak demand in gpm (excluding shower heads) ¹
1 to 5	1.5 to 7.5
6	8.0
7	10.1
8	11.2
9	12.0
10	12.8
12	14.3
14	15.5
15	16.0
16	16.5
18	18.0
20	18.7
25	20.2
30	21.5
40	24.0
50	25.0
60	26.0
70	26.6
80	27.1
90	27.6
100	28.1
110	28.5
120	28.9
130	29.3
140	29.7
150	30.0
150 or more ²	

¹To determine total peak demand, add 1 gpm for each shower head.

²To determine total peak demand for systems with over 150 outlets, allow 0.2 gpm for each outlet except showers, plus 1 gpm for each shower head.

from the tanks or sumps by a fire pumper or skid-mounted pump.

(3) **Water-consumption data.** In planning and designing water-supply and distribution systems, the type of project to be supplied and its size, based on the expected population, are the primary considerations. If consumption data are known, basic requirements can be calculated from table 4-5. Water-consumption data are also necessary for development of the source and storage facilities, design of the distribution system and pumping plants, and selection and design of treatment plants. Storage facilities should be designed to hold at least 50 percent of 1 day's water requirements.

(a) **Areas without sewers.** In Army installations without sewers, the basic per capita consumption is 5 gallons per day.

(b) **Industrial areas.** In industrial areas, requirements average about 100,000 gallons per acre per day.

(c) **Family quarters.** Each resident of permanent Army installations requires a minimum of 60 gallons per day, including an allowance for waterborne sewage. In the average family-quarters area, minimum consumption occurs on Sundays and peak consumption on Mondays. The highest demand for water occurs from 0700 to 0900 and from 1700 to 1930. Minimum demand occurs at 0400 hours.

(d) **Calculating consumption.** When calculating consumption requirements for systems such as company bathhouses or hospital utility buildings, the number of water outlets and shower heads should be considered. The peak water demand for any area or building served by a distribution main is determined by allowing 1 gallon per minute for each shower head, and 1.5 gallons per minute for each of the other outlets. Theoretically, at an allowance of 1.5 gallons per minute per outlet, a peak demand would equal outlets times allowance per outlet. But experience indicates that the greater the number of outlets, the lower the probability of their all being used simultaneously. Therefore, for design purposes, peak demands are reduced in a

TABLE 4-5. Per-Capita Water Allowances for Design of Facilities

User	Conditions	Gallons per day	Remarks
Men	Drinking and cooking only	5	No water for bathing or flushing purposes.
	Temporary camp with waterborne sewage	25	Includes bathing.
Hospital	Drinking and cooking only	25	No water for bathing or flushing purposes.
	With waterborne sewage	50 (per bed)	Includes water for medical personnel.
Animals	Average	10	
Vehicles	Level or rolling country	½	Does not include washing.

ratio to the total number of outlets. The peak water demands for a given number of outlets (excluding shower heads) are contained in table 4-4. Service connections in buildings must be capable of supplying the peak demand. The size of distribution mains serving several buildings is determined by the total shower demand, plus the total demand of all other outlets. Service connections and mains should be large enough to deliver the required flow under the available pressure.

b. Pressures.

(1) Working pressures for conveying water through mains vary with the permanency of the installation and the equipment available. In the field, pressures from 20 to 70 psi are ordinarily satisfactory.

(2) Distribution lines should deliver peak water demands to areas served by individual mains with at least a 20-psi working pressure at the service connection. Working pressures above 100 psi increase the breakage and maintenance on fittings and fixtures and water hammer may occur at 100 psi. Excessive distribution pressures may be reduced by pressure reducers and pressure relief valves.

(3) Nomographs and similar scales are used for designing water-distribution systems. If any two

factors in a nomograph are known, a straightedge placed across them, as in figure 4-9, indicates the unknown factor.

(4) Doubling the diameter of a pipe increases the cross-sectional area four times, and increases its capacity between six and seven times.

c. Friction losses. Friction losses in service connections and distribution mains are normally based on the use of iron or steel pipe, using a C coefficient of 120. If the installation is expected to be in use more than five years, the coefficient of 100 should be used.

4-8. SURVEYS AND MAPS

The need for surveys is established by reconnaissance, by the extent and accuracy of existing maps, and by data needed to complete designs.

Topographic maps should be prepared to a horizontal scale of 1 inch equals 10 feet, with 1-foot contour intervals at intakes, pump stations, and treatment plants. Allowable horizontal error in alignment and profile surveys is 1 in 5,000. Vertical levels are read to one-tenth foot on the ground or one-hundredth foot on bench marks, turning points, and existing permanent structures. If Government bench marks are not convenient, an arbitrary reference point must be estab-

lished. Locations and layouts of all pipelines and structures are plotted on profile sheets and topographic maps. Established pipeline profiles and hydraulic grade lines are plotted on profile and map sheets, or may be separate drawings.

4-9. TYPE AND SIZE OF PIPE

a. The design of mains and service pipes for theater of operations distribution systems is limited by the type and size of available pipe. Working pressures and other features of the supply and distribution system must be established by the designer to suit the characteristics of the available pipe and pumps.

b. Pipe is shipped overseas in a limited number of standard sizes and types. Interior plumbing and service pipes of steel or bituminized fiber may be available in 3/4-, 1- 1 1/3 2-, 4-, 6-, and 8-inch sizes.

4-10. PIPELINE DESIGN

Pipeline design consists of determining one of the following factors when the other two are known: head, pipe size, and discharge.

a. Definitions.

(1) **Available head.** The available head is the head causing flow through a pipe. It may be obtained by gravity, by pumping, or by a combination of both.

(a) In a gravity system, the difference in elevation between the water surface at the inlet and at the outlet is the gravity head, and constitutes the entire available head.

(b) In a pumping system on flat terrain, the pump discharge head is the available head.

(c) In a pumping system on uneven terrain, the difference in elevation (gravity head) between the pump and the outlet of the pipeline must be included. Where the outlet is lower than the pump, the available head is the pump discharge head plus the gravity head. Where the outlet is higher, the available head is the pump discharge head minus the gravity head.

(2) Permissible head loss.

The available head in feet divided by the length of pipeline in thousands of

feet is the permissible head loss in feet per thousand feet. If the pipeline is short, the effect of fittings should be included.

(3) **Economical velocity.** To avoid excessive pump horsepower, usual flow velocities for pumping systems are between 3 and 6 fps. For gravity systems, velocities are limited only by the available head.

b. **Simple pipelines.** A simple pipeline is the same diameter throughout its length and does not have any branch lines. Simple pipelines may be designed by using the nomograph in figure 4-9.

c. Example.

Given: Gravity system; water surface at outlet 100 feet below water surface at inlet; required flow 500 gpm; length of line 16,000 feet; new iron pipe (friction factor $C = 120$).

Find: Pipe size.

Solution: permissible head loss is--

$$\frac{100}{16} = 6.25 \text{ feet per 1,000 feet.}$$

The nomograph (fig 4-9) shows an 8-inch pipe is satisfactory.

d. **Compound pipeline.** Compound pipelines (fig 4-11) may be a series compounded, parallel compounded, or series-parallel compounded. Different size pipes connected in series are series compounded. Pipes of the same size or of different sizes connected in parallel are parallel compounded. Parallel compounded lines connected to either simple or series compounded lines are series-parallel compounded. In solving problems involving compound pipelines, first reduce the compound pipeline to an equivalent simple pipeline. In other words, find the pipe of a given diameter which gives the same total head loss as the compound line. Flow problems are then solved as for the simple pipeline. Table 4-6 gives factors for converting a pipe length of a given size to an equivalent length of another size. Figure 4-12 shows a branching pipeline system where discharges are known,

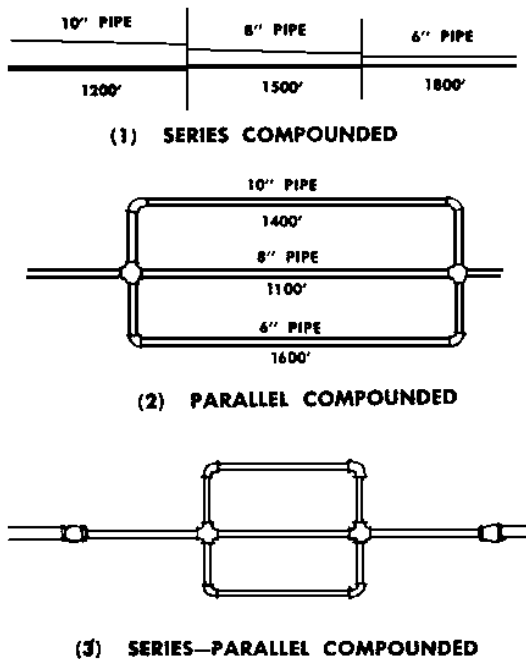


Figure 4-11. Compound pipelines.

and figure 4-13 shows a system where pipe sizes are known.

4-11. OPERATION AND MAINTENANCE

a. Importance of maintenance.

Failure of water supply systems often is attributed to defective equipment when improper plant operation and maintenance by unqualified personnel are the true causes. Pump operators must be familiar with the mechanical features and safe operation of their equipment; treatment-plant operators must understand the physical processes of water treatment and have some knowledge of the chemistry involved; and all operators must be alert to detect and correct sources of trouble before they occur.

b. Pumps. Operation, maintenance, lubrication, and parts manuals are available for all standard types of depot-stocked equipment. In general, pump operation consists of pumping against the full head that gives the highest pump efficiency; pump maintenance consists of lubrication, and eliminating air or

TABLE 4-6. Factors for Converting Pipe of a Given Diameter to an Equivalent Length of Pipe of a Different Diameter

To From	3/4"	1"	1 1/4"	1 1/2"	2"	4"	6"	8"	10"	12"
3/4"	1	4.06	11.9	20.3	119.	3,500.	25,200.			
1"	.246	1	2.96	7.21	20.3	860	6,210			
1 1/4"	.0638	.338	1	2.43	9.00	290	2,100	8,510		
1 1/2"	.0342	.139	.412	1	4.06	119	860	3,500	10,300	
2"	.0083	.0342	.101	.246	1	20.3	212	860	2,520	6,210
4"		.00116	.000345	.00830	.0342	1	7.21	29.3	86	212
6"			.000476	.00116	.0047	.139	1	4.06	11.9	29.3
8"			.000118	.000286	.00116	.0342	.246	1	2.93	7.21
10"					.000396	.0116	.0839	.342	1	2.46
12"					.000161	.00472	.0342	.138	.406	1

water leaks. Vapor or air locks reduce or stop the output and may cause pumps to overheat. The pressure gage on the pump outlet, which indicates line pressure, must be watched closely. Head loss due to a line opening or an increase in pressure caused by a stoppage or a closed valve is quickly indicated on the gage. The power unit must be fueled, lubricated, and provided with cooling water. In freezing weather, precaution must be taken to prevent

ice from bursting the equipment or causing stoppages. The pressure-release valve must be working properly in displacement-pump systems to prevent breakage due to increasing pump pressure caused by line shutoffs. Any increase beyond the normal maximum pressure should be counteracted immediately by reducing pump speed or stopping the pump entirely and opening the waste valve. The trouble then can be located and corrected.

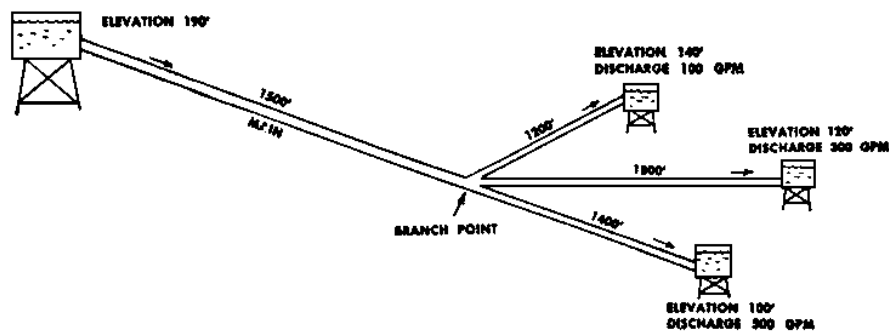


Figure 4-12. Branching pipeline system where discharges are known.

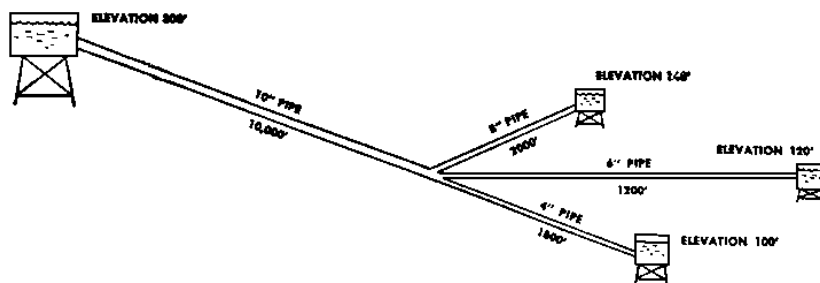


Figure 4-13. Branching pipeline system where pipe sizes are known.

c. Treatment plants. Plant operation and maintenance necessarily vary with the type of installation. Operating manuals for the mobile and portable purification units are useful in operating all systems, but in larger fixed installations each process must be studied carefully to determine the most efficient operating procedure. The physical processes and chemistry of purification are explained in TM 5-700.

(1) Rate of flow, length of the retention period, accumulation of sludge, and the amount of chemicals used in coagulation and disinfection must be checked closely.

(2) In freezing temperatures, adequate velocities must be maintained to prevent ice formation. In extremely cold climates, tanks and

filters should be enclosed in a heated building.

d. Pipes and distribution systems.

The pipe and distribution system should be patrolled regularly to detect leaks or unauthorized connections and to test the operation of valves. Sludge and organic growth which accumulate in low velocity line should be flushed out occasionally by increasing pressure during a low consumption period and then opening blowoff valves to obtain a maximum velocity of flow. Various types of mechanical cleaners are used to remove rust and other incrustation. Such processing is usually not required for several years after the line is laid. Valves at branch or main intersections must be adjusted properly to equalize pressures and assure service to the ends of the line.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space provided below each question. When you have finished answering all the questions for this lesson, compare your answer with those given for this lesson in the back of this booklet. Review the lesson as necessary. Do not send in your solutions to these review exercises.

1. Prior to the development of detailed plans for the construction of a water supply and distribution system in a theater of operations, what guidance must the responsible officer consider? (Para 4-2b)

2. Stage construction is the procedure followed when a project is completed either by units or by levels of improvement. How is stage construction useful in a utilities project? (Para 4-2c(6))

3. The depth of water required to produce a given pressure is termed "head." How many feet of head are required to produce a water pressure of fifty pounds per square inch? (Para 4-3d)

4. In a column of water having a thirty foot head, what is the difference in pressure between the midpoint and the bottom of the column? (Para 4-3e)

5. Explain the difference between atmospheric (or gage) pressure and absolute pressure. (Para 4-3f)

6. Ignoring increase in friction loss, how many feet of additional head will be required to increase the velocity of flow from 16 fps to 28 fps? (Para 4-3h(1))

7. What is the friction-head loss in a 2,500 foot length of six-inch pipeline carrying 100 gallons per minute? (use $C = 100$) (Para 4-3h, fig 4-3)

8. Pipe fittings such as bends and tees also contribute to the head loss in a water distribution system. How are head losses for these type items calculated? (Para 4-3h(5), fig 4-4)
9. Give the definition of static head. (Para 4-3i)
10. Using the surface-velocity method, what is the discharge in cubic feet per second in an open channel six feet wide if the average stream depth is 1« feet and the observed surface velocity is 4 feet per second? (Para 4-4a)
11. What head in inches will be required to discharge 1,000 gallons per minute from a triangular weir having a 90ø notch? (Para 4-4b(4))
12. What discharge can you expect from a new 6-inch iron pipe ($C = 120$) at a maximum permissible friction loss of 4 feet per 1,000 feet? (Para 4-5b, fig 4-9)
13. What is the velocity of flow in the pipe described in exercise 12? (Para 4-5, fig 4-9)
14. What is the most essential requirement of the water supplied to an Army installation by any water-distribution system? (Para 4-6a(1))
15. Name the three basic types of water supply and distribution systems. (Para 4-6b)
16. What are the primary considerations in planning and designing water-supply and distribution systems? (Para 4-7a(3))

17. When preparing topographic maps, for use in laying out water supply and distribution systems, what horizontal scale should be used? (Para 4-8)

18. Working pressures of water supply and distribution systems in a theater of operations will usually depend upon what factor? (Para 4-9a)

19. Velocity of flow in a pipe is dependent upon available head. When the head is provided by pumping, what velocity range should be observed for economical reasons? (Para 4-10a(3))

20. If the gage on the pump outlet indicates a pressure beyond the normal maximum, what action should the operator take immediately? (Para 4-11b)

LESSON 5

PLUMBING INSTALLATIONS AND BILLS OF MATERIALS

CREDIT HOURS	4
TEXT ASSIGNMENT.	Attached memorandum.
MATERIALS REQUIRED	None.
LESSON OBJECTIVE	Upon completion of this lesson on plumbing you should be able to accomplish the following in the indicated topic areas.

- 1. Description of plumbing system.** Describe a plumbing system, including all fixtures and equipment involved, and define all special terms used in plumbing.
- 2. Planning.** Explain the fundamentals of planning for a plumbing project, the layout, determining water requirements both hot and cold, and selection of pipe sizes to be used.
- 3. Waste disposal.** Explain the housedrain plan including the purpose for and location of traps, vents, cleanouts, and any other appurtenances.
- 4. Plumbing materials.** State the type of material used in pipe as related to the use and location of the pipe, weights and strength of pipe, types of joints, fittings, and fixtures.
- 5. Bill of materials.** Describe the procedure to be followed in developing an accurate and useful bill of materials for a plumbing project.
- 6. Safety.** Cover safety rules as applicable to plumbing projects.

ATTACHED MEMORANDUM

5-1. INTRODUCTION

a. The plumbing system for a building plays a very essential part in today's living. It includes all pipes, fittings, and fixtures which are used to provide water and to remove water-borne sewage. The supply pipes of the system bring into the building a supply of wholesome water, and the drainage pipes carry off the used water. Sanitation and health as well as comfort and convenience are served. Because of the health hazards resulting from impure water and improper drainage, care and knowledge must be exercised in installing a plumbing system.

b. Plumbing has two objects: (1) to furnish water to the various parts of

a building; (2) to remove the liquid wastes and discharge them into the sewer or other disposal installation. The waste system, in turn, must provide quick removal of the wastes with minimum chance for stoppage of drains and must keep vermin and sewer "gas" out of the building through the use of properly vented traps.

c. Sewer "gas" is not actually a gas of definite chemical composition but air which has come into contact with decomposing organic matter. The sewer air may contain some of the gases which are the results of decomposition, and which, in some places such as unventilated sewers or sewer manholes, may overcome workmen. Numerous

bacteriological tests have shown that sewer air is as free from bacteria as ordinary air, and that no disease or infection need be feared from sewage bacteria floating into houses with sewer "gas". But the matter cannot be dismissed lightly. No one can say with certainty, for example, that long exposure to sewer air will not have some harmful psychological or, perhaps, physiological effects. Hence, both safe practice and good sense dictate that sewer air be prevented from entering buildings.

d. A plumbing system, in its simplest form, consists of one supply pipe leading to a fixture and one drain pipe taking the waste water away from the fixture. In most cases the fixture is supplied by two pipes, one for hot and one for cold water, and the drain pipe is usually vented. An increase in the number of fixtures increases the complexity of the drainage system and frequently requires the installation of additional vent pipes. When the functions of these supply, drainage, and vent-pipe systems are understood and each is considered independently of the other, a plumbing system becomes easier to comprehend.

e. Definitions of terms are as follows:

(1) **Building plumbing.** Water supply and sewage disposal fixtures, equipment, and pipes used to distribute water and collect drainage and

sewage within a building and 5 feet outside the building (fig 5-1).

(2) **Building main.** Water supply pipe and fittings from the water main or other source of supply to the first branch of the water-distribution system (fig 5-1).

(3) **Building sewer.** Sewer pipe extending from a point 5 feet outside the building to street sewer or other disposal system (fig 5-1).

(4) **Building drain.** Lowest horizontal piping of the building drainage system receiving discharge from soil, waste, and other drainage pipes. It is connected to the building sewer (fig 5-1).

(5) **Branch.** Any part of a water supply system other than the main used in the building (fig 5-2).

(6) **Fixture branch.** Supply pipe between a fixture and the building main or building piping (fig 5-2).

(7) **Fixture drain.** Drain pipe from a fixture trap to the main drain pipe or building drain (fig 5-2).

(8) **Air gap.** Vertical distance between supply fitting and highest possible water level in a fixture with fitting supplies.

(9) **Backflow.** Flow of water into a water supply pipe from any source except its regular one. An air gap will prevent backflow.

(10) **Stack.** Vertical pipe of the soil-, waste-, or ventpipe system (fig 5-3).

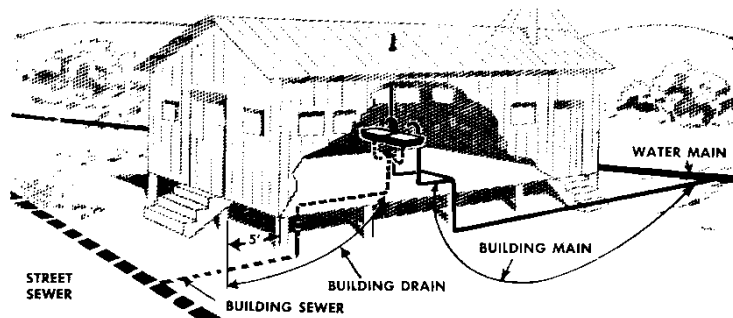


Figure 5-1. Building plumbing layout.

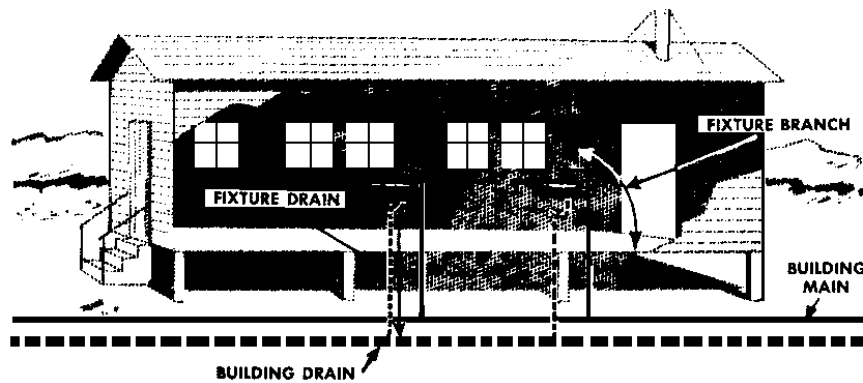


Figure 5-2. Fixture pipe layout.

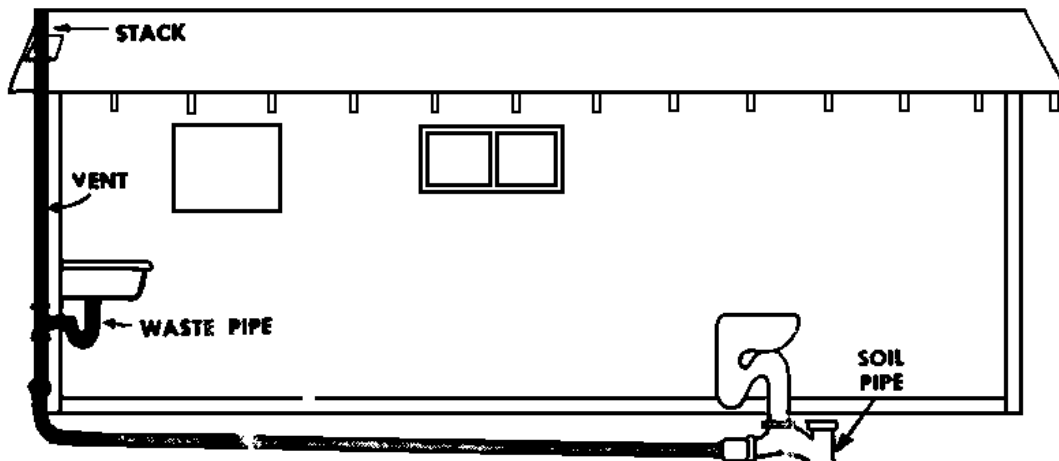


Figure 5-3. Drain installation.

(11) **Vent.** Pipe open to the atmosphere, which provides ventilation for a drainage system and prevents trap siphonage or back pressure (fig 5-3).

(12) **Soil pipe.** Pipe carrying discharge from water closets and similar fixtures. It may serve as a waste or vent pipe at the same time (fig 5-3).

(13) **Waste pipe.** Pipe carrying water from wash basins, sinks, and similar fixtures.

(14) **Trap.** Fitting that provides a water seal to prevent sewer gases and odors being discharged back through fixtures (figs 5-4 and 5-8).

(15) **Cleanout.** Plug or similar fitting to permit access to traps or sewer lines. Cleanouts are usually used at turns and other points of collection (figs 5-5 and 5-8).

(16) **Stub-in.** Temporary fitting which caps a pipeline running to a fixture until the fixture is installed (fig 5-6).

(17) **Fixtures.** Receptacles such as basins, or sinks, that receive and discharge liquid or waterborne wastes (fig 5-7).

(18) **Fittings.** Parts and materials of piping system used to make bends in pipe-lines, branches, and connections; to seal pipes; and to attach fixtures (fig 5-8).

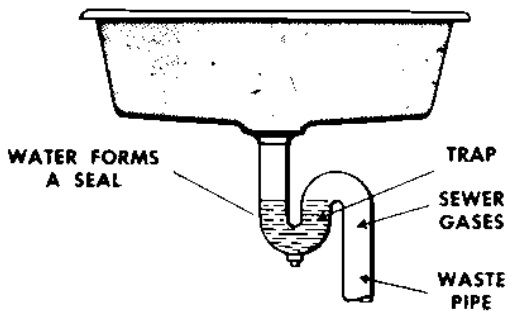


Figure 5-4. Trap.

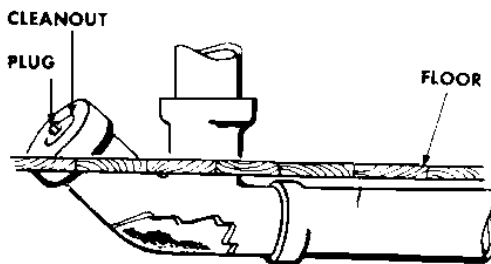


Figure 5-5. Cleanout.

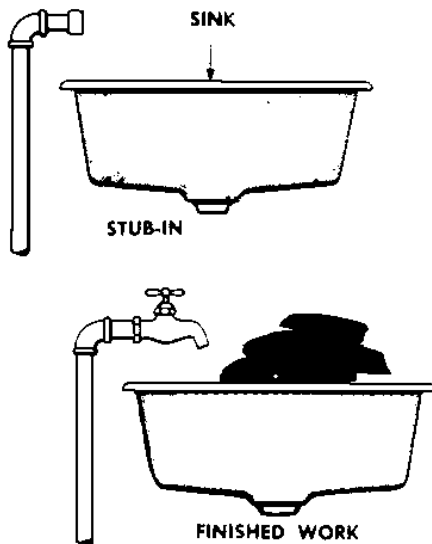


Figure 5-6. Stub-in.

(19) **Elbows (bends).** Fittings which change pipe direction. Elbows are classified by angle of direction change; bends, by the portion of the circle which they form. Thus, 90°

elbows are quarter bends, 45° elbows are eighth bends, and so on (fig 5-8).

(20) **Roughing-in.** Installing supply and waste pipes without installing fixtures. This minimizes damage to fixtures during construction.

(21) **Water closet.** Term used to indicate standard issue toilet (fig 5-7).

(22) **Water supply.** Plumbing for water supply includes the building main, supply piping to fixtures and faucets, and necessary valves, fixtures, and fittings (fig 5-4).

(23) **Drainage system pipework.** The building drainage system includes waste pipes, vent stacks, floor drains, and building lateral to sewer. Vent stacks are usually run outside the building. In cold climates, the stack size should be increased to prevent freezing (fig 5-8).

(24) **Riser.** A riser is a vertical water supply pipe which carries water to branches in upper stories.

(25) **Fixture unit.** A fixture unit is a factor so chosen that the load-producing values of the different plumbing fixtures can be expressed as multiples of that factor.

5-2. PLUMBING FUNDAMENTALS

Basic practices which apply to any plumbing job are as follows:

- a. Save material, eliminate unnecessary branch lines, and run pipe on shortest practical path.
- b. Lay pipe where it is accessible for repair and cleanout.
- c. Keep bends and fittings to a minimum to avoid loss of pressure and to prevent clogging.
- d. Install horizontal drainage pipes with at least a ¼-inch fall per foot for 2-inch pipe, 1/8-inch fall per foot for 4-inch pipe, and 1/16-inch fall per foot for 5- to 8-inch pipe.
- e. Do not run water or drainage pipe electrical equipment unless equipment is protected.

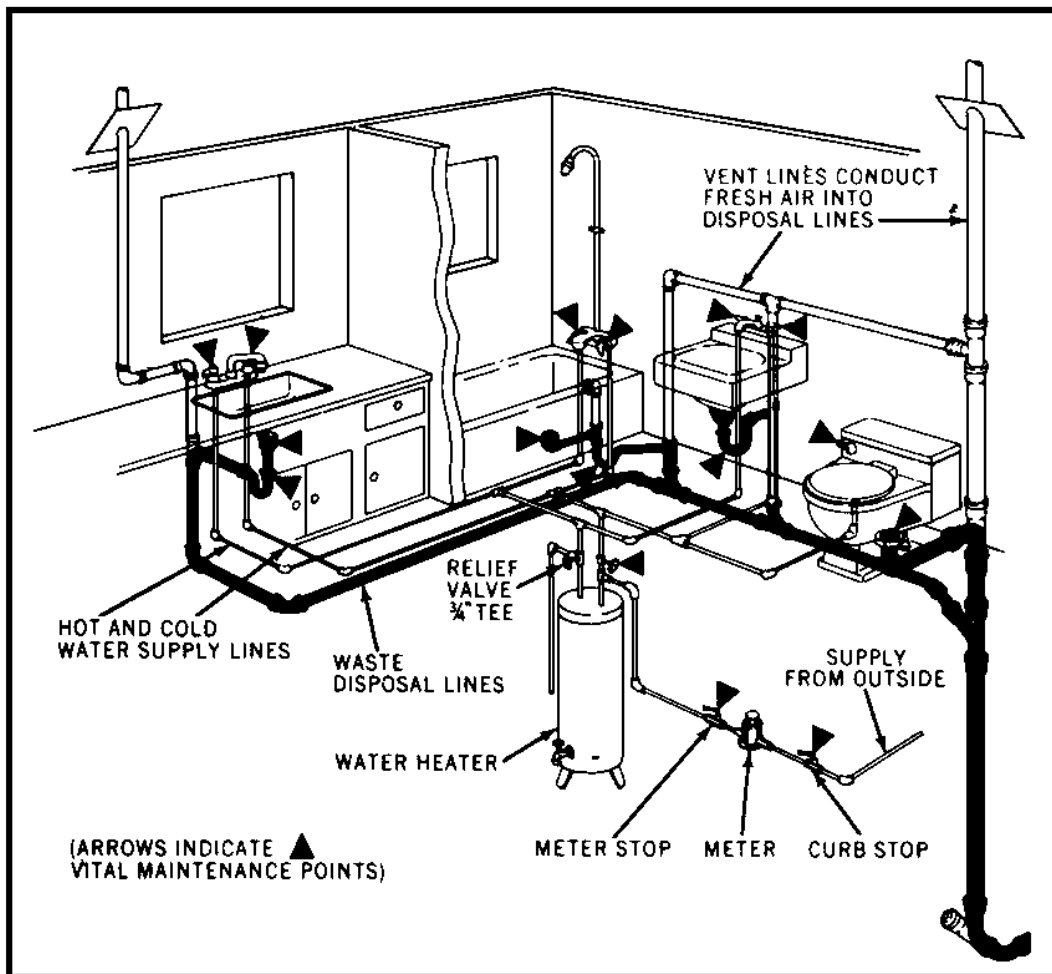


Figure 5-7. Water supply and drainage installation.

f. Do not install drainage pipe over an uncovered water supply tank or food-processing area.

g. Do not install cross connection between a water supply system carrying drinking water and a water supply system carrying water of lower sanitary standards.

5-3 PLANNING

a. Layout. The layout of a plumbing system, within the scope of the job directive, should be simple enough to make fixtures and units accessible and, at the same time, flexible enough to permit future expansion. Proper layout facilitates the preparation of accurate estimates,

minimizes interference with other work, and helps to insure a safe and sanitary installation (fig 5-9).

b. Piping diagrams. A piping or riser diagram gives a relatively complete picture of the plumbing system (fig 5-10). It is usually a drawing showing all pipe, fittings, and fixtures as nearly to scale as possible. It may be schematic and show connections of all fittings. When used with a plumbing layout, you can estimate the amount of pipe required for any plumbing installation.

c. Tempered lines. The piping diagram in figure 5-10 shows only one line to the showers and lavatories. This is known as a

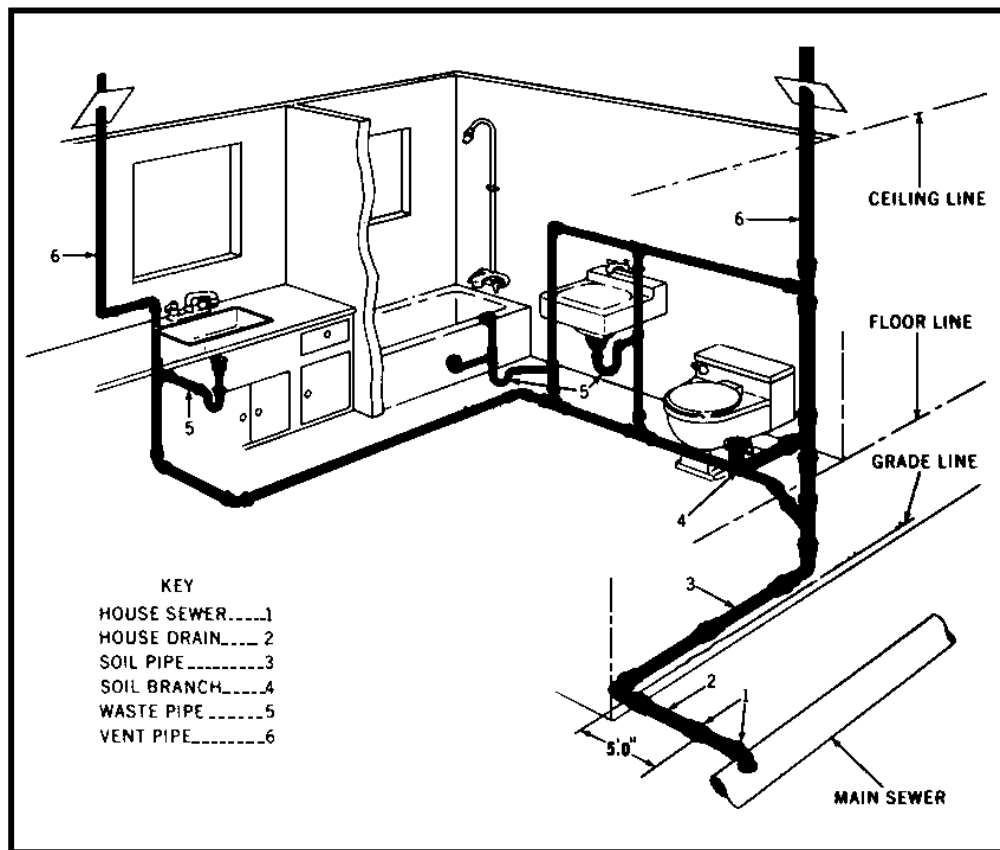


Figure 5-8. Drainage and disposal system.

tempered line, in which hot and cold water are mixed in a master valve with a thermostat control. Its chief drawback is the lack of a temperature adjustment at the fixture. Remember that tempered lines are expedient measures to save pipe and fittings, and that separate hot and cold lines to fixtures are preferred if materials are available.

d. Design considerations. The appropriate distribution of water within a building is of paramount importance. You must determine, from studies of water-requirements tables and from estimates based on factors included in table 4-4, paragraph 4-7, of lesson 4, how much hot and cold water is required for a particular installation. These requirements, are prerequisite to the layout and design of any water-supply system, since, for

example, a system designed to supply 300 gallons of water in 8 hours differs in many ways from one with a requirement of 300 gallons per hour.

e. Hot-water systems. Hot-water systems vary in design according to the function of the building. In each system, the circulation is continuous. Cold water enters the bottom of the tank and is drawn off at the top. Each heater has a temperature-and-pressure-relief valve (also known as a safety or pop-off valve) and a drain valve. Unions are provided to facilitate the removal of the tank for repairs or replacement. Hot-water systems use coal, electricity, fuel oil, or gas as a source of heat. The capacity of a hotwater heater is measured by its output of hot water in gallons per hour. For example, the re-

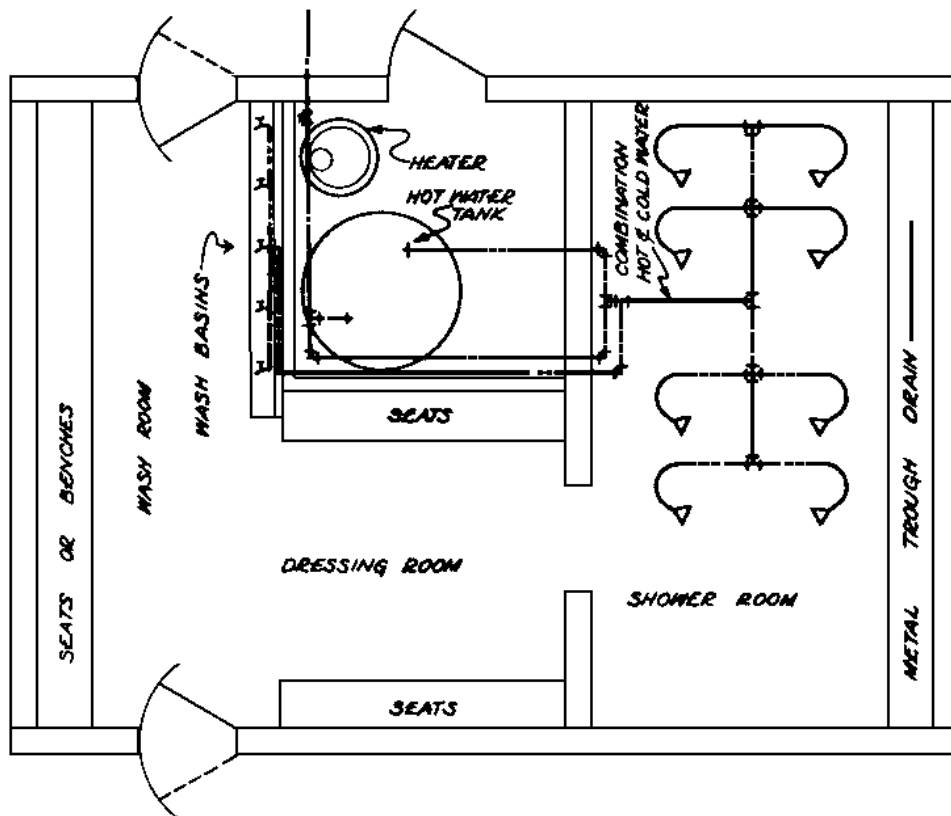


Figure 5-9. Plumbing layout for a company bathhouse.

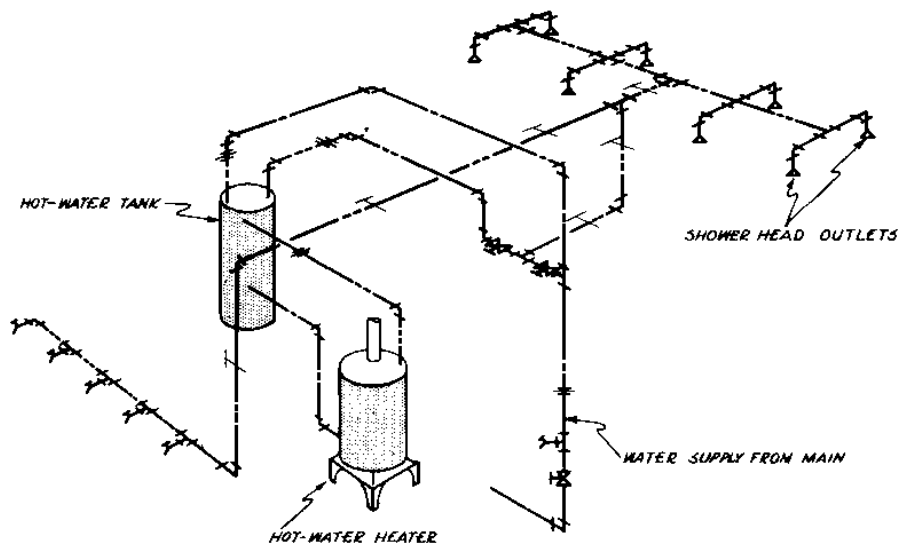


Figure 5-10. Piping or riser diagram for a company bathhouse.

quired capacity of a heater for a company messhall is 50 gallons per hour, while that for a company bathhouse is 300 gallons per hour.

f. Persons per fixture. Table 5-1 shows permissible number of persons per fixture.

5-4. DETERMINING PIPE SIZE

Water supply and drainage pipes must be large enough to provide water and adequate drainage of wastes yet not exceed the size required for maximum flow. Sizes available in a theater of operations are 3/4-, 1-, 1 1/4-, 2-, 4-, 6-, and 8-inch diameter pipe.

a. Sizing the water service.

(1) Factors. Among the factors which determine the size of the water service in a plumbing installation are the types of flush devices used on the fixtures, the pressure of the water supply to the building in pounds per square inch, the length of piping in the building (creating friction loss), the number of fixtures installed in the building, and the probable use factor of these fixtures. When a liquid flows through a pipe, particles of the liquid stick to the pipe wall and do not move. Other particles moving past are slowed down

TABLE 5-1. Permissible Number of Persons Per Fixture

	Water closets	Lavatories	Urinals	Showers	Bathtubs	Drinking fountains
Enlisted men's barracks -----	20	8-9	16-18	24	—	75
WAC barracks ¹	6-8	6-7	—	10	25-30	50-75
Nurses' quarters ²						
Telephone operators' quarters Civilian women's quarters						
Officers' quarters ³ -----	6-7	6-7	9-11	8-10	—	50-75
Cadet officers' quarters -----	6-7	6-7	9-11	8-10	—	50-75
Industrial buildings, shops, hangars, warehouses -----	20	20	40	—	—	50-100
Theaters and assembly halls:						
Male -----	300	200	300			
Female -----	200	200	—			
Chapels:						
Male -----	300	150	300			
Female -----	150	150	—			
Classrooms -----	50	50	50	50	—	200
Hospitals:						
Patients -----	8-10	5-7	18-20	18-20		
Employees -----	25	25	40			
Administration and similar buildings ⁴ :						
Up to 10 people -----	5	5	10	—	—	10
11 to 16 -----	8	8	16	—	—	16
17 to 25 -----	9	9	25	—	—	25
26 to 100 -----	15	15	30	—	—	50
Over 100 -----	20	20	40	—	—	75
Mess halls ⁵						
Kitchen personnel (hospital):						
Male -----	20	10	40	1	—	—
Female -----	10	10	—	1	—	—

¹ One single-compartment laundry tray for every 20 persons.

² Minimum of one shower and one tub in each toilet room.

³ Shower for each toilet room in hospital messes only. (Required only in main toilet rooms for employees.)

⁴ The proportion of fixtures for women's toilets is the same as required for men with the addition of one water closet for each urinal omitted.

⁵ One glass-all fountain should be provided for each cafeteria serving line. Kitchen personnel for hospitals is 63 people for each 1,000-bed capacity. The kitchen personnel for troop, WAC, and civilian messes is determined by multiplying the total service capacity of the mess by the following factors: up to 600, total service capacity factor = 0.046; above 600, total service capacity factor = 0.03.

when they rub against the motionless particles. The stream of water in a pipe can be pictured as made up of a series of layers moving at different speeds, with the center moving fastest. The resistance to flow caused by the rubbing together of the particles in these imaginary layers is called pipe friction. Pipe friction causes a drop in the pressure of the water flowing through the pipe. In a small pipe this friction loss may be overcome by supplying water at a higher pressure than would otherwise be required. In a location where higher water pressure is not available, friction loss may be reduced by increasing the size of the pipe. The two most important factors in sizing the water service are the determination of the maximum fixture demand in gallons and the determination of the factor of simultaneous use. The maximum fixture demand in gallons is the total amount of water which would be required to supply all fixtures in the plumbing installation if they were operated simultaneously for a period of 1 minute. Since it is highly improbable that all fixtures will be turned on at once, a probable percentage of the fixtures which will be in use at any given time must be determined. This is the factor of simultaneous use. This figure is not exact, but may be estimated closely. The more fixtures installed in a building, the smaller the possibility that all of them will be in use at the same time. Therefore, simultaneous use factors decrease in proportion to the increase in the numbers of fixtures installed.

(2) Maximum fixture demand. To determine the maximum fixture demand in gallons, the number and type of all fixtures in the complete plumbing installation must be known. Table 5-2 is then used to obtain the maximum fixture demand. For example, assume a plumbing installation of three urinals, two water closets, one slop sink, two shower stalls, one kitchen sink, one laundry tray, and four lavatories. From table 5-2 it may be determined that the maximum fixture demand is 315 gallons per minute. The probability that all of these fixtures would be used at the same time is remote. Under ordinary circumstances only a small percentage would be in use simultaneously.

TABLE 5-2. Fixture Demand

Fixture	Units*	Gallons per minute
Water closet	6	45
Urinal	5	37 1/2
Slop sink	3	22 1/2
Shower	2	15
Laundry tray	2	15
Bathtub	2	15
Kitchen sink	2	15
Lavatory	1	7 1/2

* 1 unit = 7 1/2 gallons per minute

The method for determining the factor of simultaneous use is discussed below.

(3) Factor of simultaneous use. The factor of simultaneous use, sometimes referred to as the probable demand on a given installation at a given time, is a conjectural figure which must be estimated. A rule of thumb for estimating the probable demand for average residences is 30 percent of the maximum fixture demand in gallons. Table 5-3 contains data for estimating the probable demand. To use table 5-3, take the actual number of fixtures installed, not the fixture unit value. Use the higher portion of the percentage ranges for the lower portion of the number of fixtures ranges. For example, five fixtures would have a probable demand of about 50 percent, while 50 fixtures would have a probable demand of about 25%.

TABLE 5-3. Factors of Simultaneous Use

No. of fixtures	Percent of simultaneous use
1-4 -----	50-100
5-50 -----	25-50
51 or more -----	10-25

(4) Selection of pipe size. The flow of water in pipelines is impeded by a number of factors. This impedance causes a loss of pressure as the water flows through the line. Complicated calculations are required to consider all the factors affecting loss of pressure in a complex system. Such calculations are beyond the scope of this subcourse. For simple systems, such as the military plumber will encounter, approximate figures are satisfactory. Tables 5-4 and 5-5 for galvanized iron pipe and copper tubing, respectively, may be

TABLE 5-4. Capacities of Pipe in Gallons Per Minute (Galvanized Iron)

a. 3/8 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	5	3	3	2	2	2	----	----	----	----
20	9	5	4	3	3	3	2	2	2	2
30	10	6	5	4	4	3	3	3	3	2
40	----	8	6	5	4	4	4	3	3	3
50	----	9	7	6	5	4	4	3	3	3
60	----	9	7	6	6	5	5	4	4	4
70	----	10	8	7	6	6	5	5	4	4
80	----	----	8	7	7	6	5	5	5	4

b. 1/2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	10	8	5	5	4	3	3	3	3	3
20	14	10	8	6	6	5	5	4	4	4
30	18	12	10	8	8	7	6	6	5	5
40	20	14	11	10	10	8	7	7	6	6
50	----	16	13	11	11	9	8	7	7	7
60	----	18	14	12	12	10	9	9	8	7
70	----	----	15	13	12	11	10	9	8	8
80	----	----	----	----	----	----	----	----	----	----

c. 3/4 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	22	14	12	10	8	8	7	6	6	6
20	30	22	18	14	12	12	11	10	10	8
30	38	26	22	18	16	14	13	12	12	10
40	----	30	24	21	19	17	16	16	15	13
50	----	34	28	24	21	19	18	17	16	15
60	----	38	31	26	23	21	20	19	18	17
70	----	----	34	29	25	23	22	21	19	18
80	----	----	36	30	27	24	23	22	21	20

d. 1 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	40	28	22	18	16	15	14	13	12	11
20	55	40	32	27	24	22	20	19	18	16
30	70	50	40	34	30	27	25	23	22	20
40	80	58	45	40	35	32	29	27	25	24

TABLE 5-4. Continued

d. 1 inch—Continued

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
50	----	65	57	45	40	36	33	31	29	27
60	----	70	58	50	44	40	36	34	32	30
70	----	76	63	54	45	42	40	37	34	32
80	----	----	65	57	47	43	39	37	35	33

e. 1 1/4 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	80	55	45	37	35	30	27	25	26	24
20	110	80	65	55	50	45	41	38	36	34
30	----	100	80	70	60	56	51	47	45	42
40	----	----	95	80	72	65	60	56	52	50
50	----	----	107	92	82	74	68	63	60	55
60	----	----	----	107	90	81	75	70	65	62
70	----	----	----	----	97	88	82	74	69	67
					105	95	87	79	74	72

f. 1 1/2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	120	90	70	60	55	50	45	40	40	35
20	170	130	100	90	75	70	65	60	55	55
30	----	160	130	110	100	90	80	75	70	65
40	----	170	150	130	110	100	90	90	80	80
50	----	----	170	140	130	120	110	100	90	90
60	----	----	----	160	140	130	120	110	100	100
70	----	----	----	170	150	140	130	120	110	100
80	----	----	----	----	160	150	140	130	120	110

g. 2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	240	160	130	110	100	90	90	80	80	70
20	300	240	200	160	150	140	130	120	110	100
30	----	300	240	200	180	160	150	140	140	130
40	----	----	280	240	220	200	180	160	160	150
50	----	----	----	280	240	220	200	200	180	160
60	----	----	----	----	280	240	220	200	200	180
70	----	----	----	----	300	260	240	220	220	200
80	----	----	----	----	---	280	260	240	220	220

TABLE 5-5. Capacities of Pipe in Gallons Per Minute (Copper Tubing)

a. 1/2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	8	5	4	3	3	2	2	2	2	2
20	12	8	6	5	5	4	4	3	3	3
30	15	10	8	7	6	5	5	4	4	4
40	17	12	9	8	7	6	6	5	5	4
50	----	14	10	9	8	7	6	6	5	5
60	----	15	12	10	9	8	7	7	6	6
70	----	----	13	11	10	9	8	7	7	6
80	----	----	14	12	10	10	8	8	7	7

b. 5/8 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	12	8	7	6	5	5	4	4	3	3
20	18	12	10	9	7	6	6	5	5	5
30	22	16	12	10	9	9	8	7	6	6
40	26	18	14	12	10	10	9	8	8	7
50	---	22	16	14	12	11	10	9	9	8
60	----	24	18	16	14	13	12	11	10	9
70	----	----	20	18	15	14	13	12	11	10
80	----	----	22	19	16	15	14	13	12	11

c. 3/4 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	20	14	10	10	8	8	6	6	6	5
20	30	20	16	14	12	10	10	10	8	8
30	36	26	20	17	15	14	13	11	10	8
40	----	30	24	20	18	16	15	14	13	12
50	----	34	28	24	20	18	16	16	14	14
60	----	36	30	26	22	20	18	18	16	16
70	----	----	32	28	24	22	20	18	18	16
80	----	----	36	30	26	24	22	20	18	18

d. 1 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	50	30	24	20	18	16	14	14	12	12
20	70	45	36	30	26	24	22	20	18	18
30	80	55	45	38	34	30	28	26	24	22
40	----	65	55	45	40	36	32	30	28	26

TABLE 5-5. Continued.

d. 1 inch—Continued

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
50	----	75	60	50	45	40	36	34	32	30
60	----	80	65	55	50	45	40	38	36	34
70	----	----	70	60	55	50	45	40	38	36
80	----	----	80	65	60	50	50	45	40	40

e. 1 1/4 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	80	55	42	37	32	30	27	25	22	22
20	110	80	65	55	47	42	40	35	35	32
30	----	105	80	70	60	55	50	45	42	40
40	----	110	95	80	70	65	60	55	50	47
50	----	----	110	90	80	70	65	60	57	55
60	----	----	----	105	90	80	75	70	65	60
70	----	----	----	110	100	90	80	75	70	65
80	----	----	----	----	105	95	85	80	75	70

f. 1 1/2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	130	90	70	60	50	45	40	40	35	35
20	170	130	100	90	75	70	65	60	55	50
30	----	170	130	110	100	90	80	75	70	65
40	----	----	155	130	115	105	95	88	80	77
50	----	----	170	150	130	120	108	100	90	88
60	----	----	----	165	145	130	120	110	105	98
70	----	----	----	170	160	142	130	122	113	106
80	----	----	----	----	170	155	140	130	122	115

g. 2 inch

Pressure at source in pounds per square inch	Length of pipe in feet									
	20	40	60	80	100	120	140	160	180	200
10	280	180	150	145	110	100	90	85	80	70
20	320	280	220	190	165	160	140	125	120	110
30	----	320	280	240	210	180	170	160	150	140
40	----	----	320	280	240	220	200	190	175	160
50	----	----	----	320	280	250	230	210	200	190
60	----	----	----	----	300	280	260	240	220	200
70	----	----	----	----	320	300	280	260	240	230
80	----	----	----	----	----	320	300	280	260	240

used with the maximum fixture demand and the factor of simultaneous use to determine the correct size of pipe for the water service line. The minimum size for the water service line is 3/4 inch, and that size should be used when calculations yield a smaller one. To continue the example is (2) above, the 14 fixtures would have a factor of simultaneous use of about 35 percent. Since the maximum fixture demand was determined to be 315 gallons per minute, the water service line must have a capacity of 35 percent of 315, or 110 gallons per minute. Assuming a length of pipe of 60 feet and a pressure at the main of 40 pounds per square inch, from table 5-4 or 5-5 it can be determined that either a 1½-inch galvanized iron or a 1½-inch copper tubing water service line would be adequate.

b. Drainage pipe.

(1) Horizontal drainage pipes.

Drainage pipe size is based on the fixture unit values of the fixtures connected to the drainage pipe (table 5-2). Table 5-6 gives the capacities of horizontal drainage pipes.

(2) Stacks. Table 5-7 lists the maximum number of fixture units which may be connected to each size stack.

5-5. LAYOUT AND INSTALLATION FACTORS

a. Layout. Figure 5-11 is a plan view of a typical hospital utility building showing the location of partitions and plumbing fixtures. This building is designed to serve the needs of personnel in two 20- by 120-foot hospital wards.

b. Outlets. There are four showers; eight washbasins; eight water closets, including six in the toilet room, one in utility room No. 1, and one in the nurses' toilet; and two urinals. Utility room No. 2 contains a hot-water heater, a storage tank, and a sink. The kitchen contains a scullery sink, and both the examination-and-treatment room and nurses' toilet have a sink.

c. Cold-water piping. By running one 3/4-inch line to each wall of the shower room, the four showers will be adequately supplied. A 3/4-inch line to each of the benches in the lavatory will supply the eight washbasins and

TABLE 5-6. Capacities of Horizontal Drainage Pipes

Size of pipe	Permissible number of fixture units		
	¼-inch fall per foot	¼-inch fall per foot	¼-inch fall per foot
1¼ -----		2	2
1½ -----		5	7
2 -----		21	28
3 (waste only) --	36	42	50
3 (soil) -----	24	27	36
4 -----	180	216	250
5 -----	400	480	560
6 -----	600	720	840
8 -----	1,600	1,920	2,240
10 -----	2,700	3,240	3,780
12 -----	4,200	5,000	6,000

TABLE 5-7. Maximum Number of Fixture Units on Stacks*

Pipe diameter (inches)	Fixture units
2	6
4	240
6	960

* No water closets are drained into stack less than 4 inches in diameter.

a 3/4-inch line will also supply the urinals. Three-quarter-inch pipe is adequate to supply the four sinks.

d. Hot-water piping. Hot-water piping is laid out like the cold-water piping except that dead ends are undesirable, and paralleling cold-water lines should be avoided if possible. Hot water in dead-end lines cools rapidly and water is wasted at the fixture until hot water arrives. Similarly, cold-water lines are heated by parallel hot-water lines, and water is wasted until cold water arrives. Connections between heaters and hot-water storage tanks should be as large in diameter and as short as possible to minimize friction, since circulation in this loop depends on the small differences between the specific gravity of hot and cold water.

5-6. WASTE DISPOSAL INSTALLATION

a. Size of building drains.

Practically all water supplied to a building is carried away

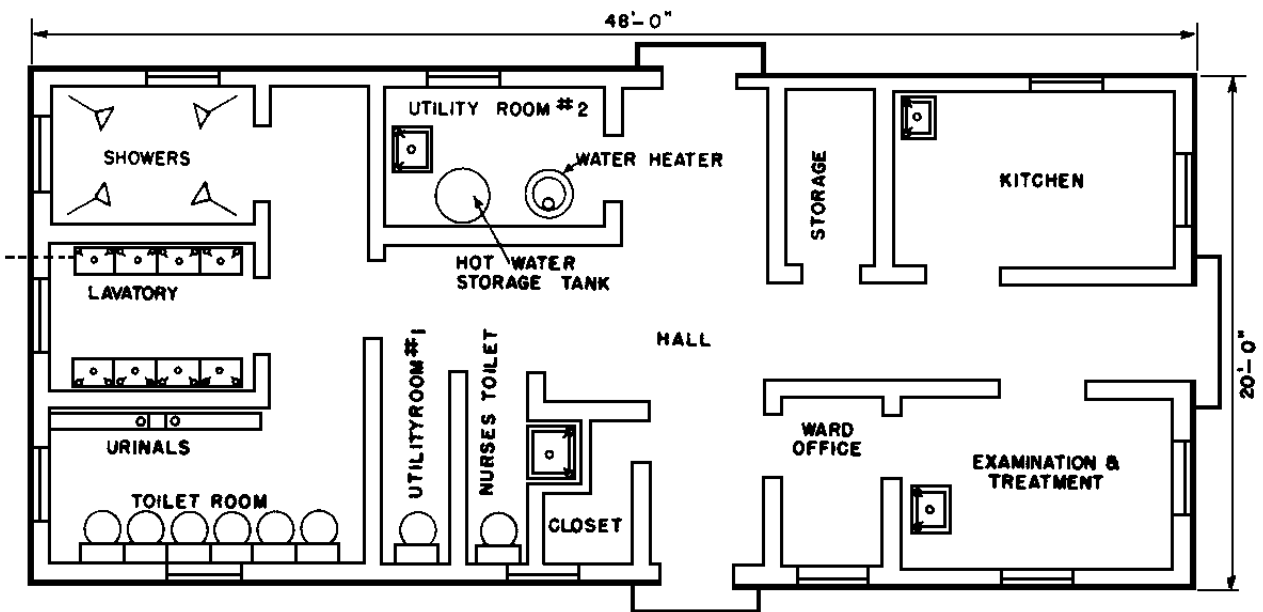


Figure 5-11. Layout plan of hospital utility building.

by the building drains. Also, the flow in drainage pipes is by gravity and not by pressure as in the case of supply lines. It is obvious, then, that waste pipes must be larger than supply lines.

b. House-drain plan. Figure 5-12 shows the house-drain plan. The waste line from the showers and lavatories will tie into the soil line from the water closets and urinals. This line may either run out to the sewer, or run across to tie into the waste line from the sink in the utility room. Another waste line will run from the sink in the kitchen to the sink in the examination and treatment room, thence either directly to the sewer or to a connection with the drain from the showers, as shown. Wastes from scullery sinks must pass through a grease trap before entering a soil or drain pipe. A single grease trap of proper size may be used for a battery of scullery sinks, and is preferably located above the floor and under or alongside the sink. In no case should wastes from fixtures other than scullery sinks pass through the grease trap. Traps, vents, and cleanouts are installed as described in this lesson.

c. Junctions. Junction of fixture connections or laterals with horizontal runs of the soil or drain system will be made with a sanitary Y-branch (par 7f). Cleanouts should be provided at strategic points on horizontal runs to facilitate the removal of obstructions. Connections from the building soil or drain system to the sewer should not be less than 6 inches in diameter, and are usually laid on a straight line at right angles to the sewer. Ordinarily, there should be one such connection per building. It is desirable to keep connections to the sewer to a minimum, because the connections must be cut in after the sewer is completed and a weak point is created in the sewer.

d. Building-sewer design. Most building-sewer systems are 4-inch, cast iron pipe, and are sloped $\frac{1}{8}$ to $\frac{1}{4}$ inch per running foot.

5-7. WASTE-DISPOSAL FITTINGS

a. Waste pipes. A waste pipe carries the discharge from any fixture, except water closets, to the soil or waste stacks, or directly to the house drain.

b. Soil pipes. A soil pipe carries the discharge of water closets, with or without the discharge of other fixtures, to the house drain.

c. Traps. A trap is a fitting constructed to prevent the passage of sewer gases and odors back through it without appreciably affecting the fixture discharge. Traps are of various designs, all of which form a water seal. The four most common traps are as follows:

(1) P-traps. The P-trap (fig 5-13) is used on a fixture when the outlet of the trap runs into the wall at a 90-degree angle to the outlet of the fixture. The P-trap is used with lavatories, sinks, urinals, and drinking fountains. It is used in some instances with shower baths and in other installations which do not require the rapid discharge of large volumes of waste water.

(2) S-traps. The S-trap (fig 5-13) is used when the trap outlet runs through the floor. One of the difficulties with the S-trap is that complete stoppage may occur in a short time. This trap is almost obsolete for Army installations.

(3) U-traps. The U-trap or running trap (fig 5-13) may be used for multiple installations such as sinks or urinals. This type of trap has its inlet and outlet continuing in a straight line in the direction of flow of the pipe to which it is connected. Previously, U-traps were installed in connection with house traps, or where area drains were trapped within a building, to prevent freezing. This practice is no longer followed.

(4) Drum traps. The drum trap (fig 5-13) is used instead of a P-trap on fixtures which pass a large volume of waste water in a short interval. The drum trap derives its name from its large diameter. Its resealing quality is greater than that of a P-trap but it has the disadvantage of being large and cumbersome.

d. Vents. A trap controls offensive odors effectively, but it does not control air pressures built up in the sewer line. Therefore,

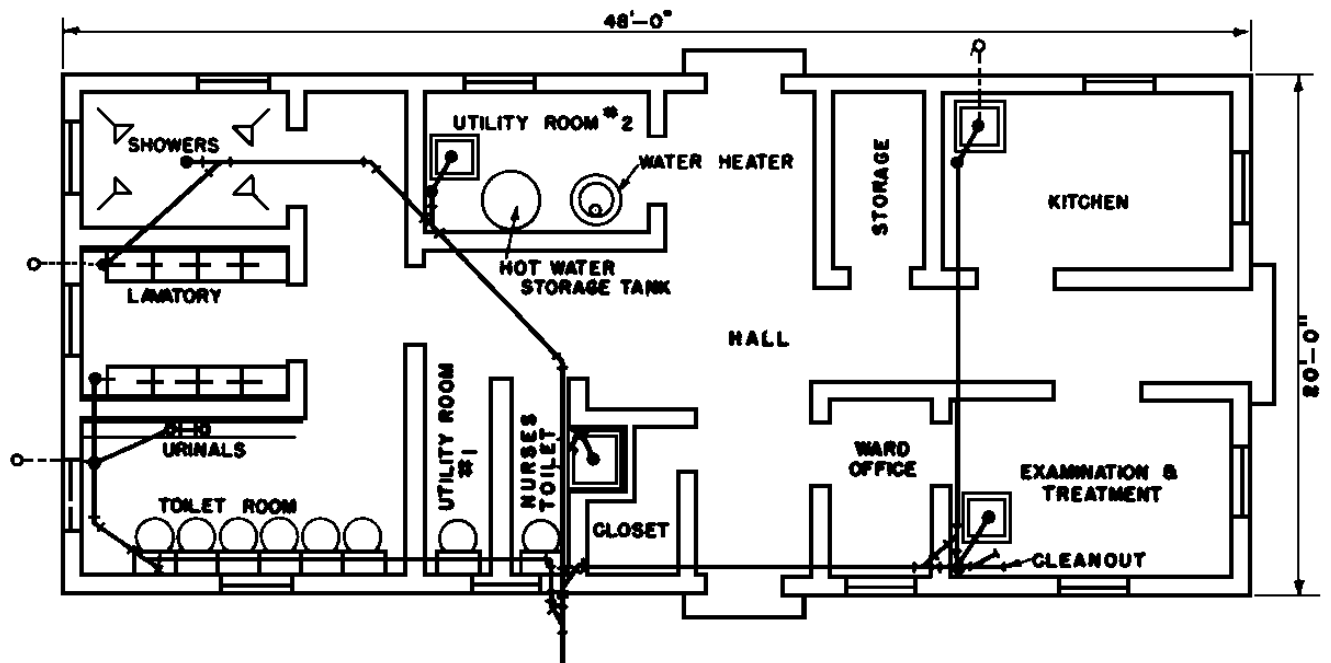


Figure 5-12. House-drain plan of hospital utility building.

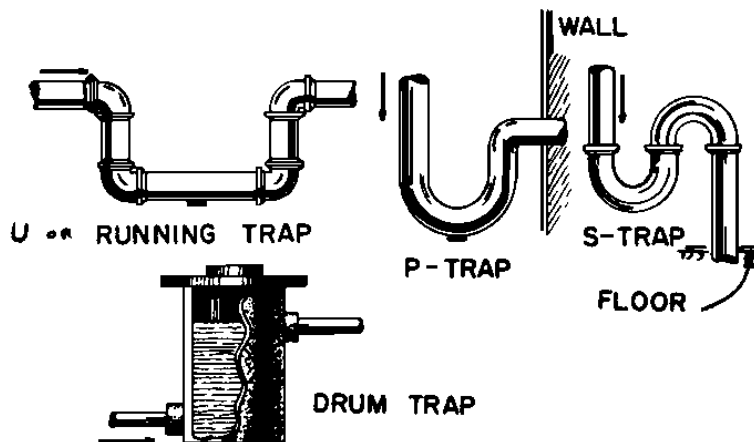


Figure 5-13. Common traps.

you should connect each trap to a vent pipe or vent stack running to the room to carry away sewer gases. Since the vent is open to the atmosphere and allows air to enter or gases to escape the system, it equalizes any existing air pressures and prevents both trap siphonage and back pressure. Vent pipes are 2 inches or more in diameter, and extend at least 1 foot above the roof of the building. Where low temperatures and heavy snowfalls are frequent, the vent pipe should be at least 4 inches in diameter, and should terminate above the maximum depth of snow. You may connect any number of fixtures to one vent pipe (fig 5-14) if it is large enough to allow free air passage and to carry the maximum waste discharge. Traps installed more than 5 feet from a vent will not function at full capacity.

e. Air gaps. Air gap is the vertical distance between the supply fitting and the highest possible liquid level in the fixture being supplied. To prevent pollution through siphonage of waste water into the water-supply line the vertical distance of an air gap should be at least 2 inches.

f. Branch lines. The sanitary Y-branches (fig 5-14) are used to connect branch lines to the building drain in order to provide minimum resistance to the gravity flow of the

sewage. They also prevent the accumulation of solids where the branch joins the main. It is good practice to install an extra Y-branch to provide a cleanout at the ends of straight runs. Obstructions in sewer lines are removed by force cups, wire brushes, closet augers, cleanout claws, scrapers, and screws.

5-8. PLUMBING IN THE THEATER OF OPERATIONS

a. General. In the theater of operations, plumbing is installed only in messhalls, hospitals, bathhouses, and other special-purpose buildings. Drainage pipes should be so designed, constructed, and maintained that waste is conducted from the fixture to the place of disposal at velocities which prevent fouling and clogging. No water or drainage piping should be located over electrical machinery or equipment unless adequate protection is provided against drip. Drainage piping should not pass over water-supply tanks, reservoirs, or food-processing or food-storage areas unless these facilities are covered or otherwise protected. Each plumbing item must satisfy the maximum number of uses. This has been accomplished by reducing the number of types, sizes, and capacities specified on standard drawings to a minimum. Figure 5-15 shows part of a typical theater of operations installation.

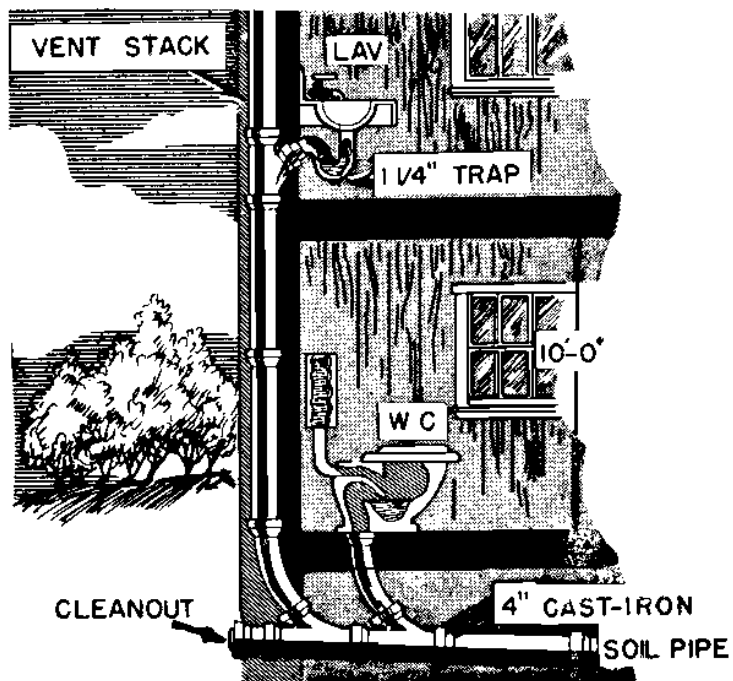


Figure 5-14. Plumbing traps and vents.

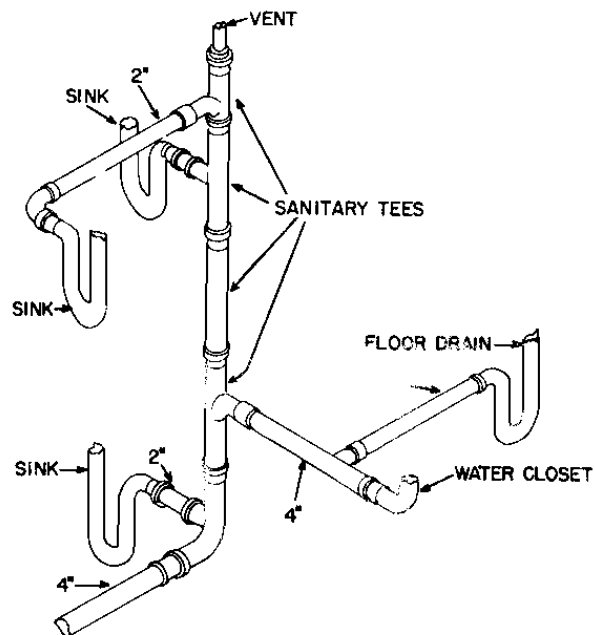


Figure 5-15. Section of typical theater of operations plumbing installation.

b. Installation.

(1) The portions of a water-supply system that are likely to freeze when an installation is not occupied should be graded to allow complete drainage during these periods.

(2) All drainage piping should pitch downward in the direction of the flow.

(3) There should be end vents on the drainage system, although venting of each individual fixture is not usually necessary.

(4) Unions should be used only where necessary for final connections.

(5) Valves should be installed on the main water-service line inside each building, or in wooden boxes outside the building below the frost line.

(6) There should be no physical connection between a water-distribution system and a drainage or waste system.

(7) Standard pipe sizes are shown in the illustrations and tables in this lesson. Pipes and fittings of other sizes (except nipples, bushings, and reducing couplings) are not for theater of operations construction.

(8) The following unit values of weights designate the loads (water consumed plus waste water discharged) of different kinds of fixtures, and are useful in estimating total loads:

Sink and lavatories	2
Service or scullery sink	3
Shower	4
Urinal	5
Water closet	10

c. Water service. The water service pipe should be large enough to furnish an adequate flow of water to meet the requirements in the building at peak demand.

d. Floor drains, traps, and cleanouts. Floor drains should meet only the actual need. Traps should be provided for each fixture or battery of fixtures. There should be pipe cleanouts at or near vertical soil and waste stacks and in each 90-degree change in direction of the drainage piping.

e. Hot-water systems. Water heaters should be installed complete with flue extending through roof. Flues shall be properly isolated from wood and should be flashed and capped. Valves must not be installed on circulating piping between heaters and tanks. Recovery capacity of water heaters for bath-houses should be from 2.5 to 3.0 gallons per hour per person, based on 50°F rise in temperature. Storage capacity for bathhouses should be from 0.75 to 1.5 gallons per person. Estimates of water-heating requirements for buildings other than bathhouses should be based on the per fixture method. The rate of flow to fixtures may be determined as shown in lesson 4. Direct water heaters are installed with range boilers or storage tanks. Hot-water generators are a combination of the coil-type heater and storage tank. Each square foot of heating surface in instantaneous water heaters and hot-water generators will heat 65 gallons per hour with a 100°F rise in temperature at a minimum steam pressure of 75 pounds per square inch.

f. Substitute construction. Since pipe clamps or pipe hangers are not included in the bills of materials and are not furnished for theater of operations installations, nails driven into firm bearing and bent around the pipes may be used as substitutes. Bailing wire, salvaged steel straps, or scrap lumber may be used for bracketing, suspending, and supporting pipes. Elbows and nipples may be used as substitutes for return bends and traps when such items are not available. Roof openings between pipe and flashing may be sealed with a mastic cement. Showers may be built without conventional shower heads by crimping the end of pipe, by using drilled pipe caps, or for showers outside buildings, by punching holes in the bottom of available POL drums.

5-9. PLUMBING MATERIALS

Various materials are used in the manufacture of pipes and fittings. Water pipes within buildings are made of wrought-iron, plain or galvanized steel, brass, or copper. The fittings used on steel, brass, and wrought-iron pipe are tapped with a standard pipe thread, whereas the fittings used on copper are of the sweat joint variety. Soil and drainage pipe are made of cast or wrought iron, plain or

galvanized steel, with threaded or calked joints. Neither plain nor galvanized steel pipe should be used for underground soil pipe.

a. Steel and wrought-iron pipes

(1) Steel and wrought-iron pipes are available in various weight classifications. These weight classes are referred to as standard, extra-heavy, and double-extra heavy, or as standard, extra-strong and double-extra strong. The current trend in civilian practice is toward the adoption of a schedule numbering system. Standard pipe roughly corresponds to schedule 40, extra-strong (heavy) approximates schedule 80, and double-extra strong (heavy) is roughly equal to schedule 160. In any case, this weight classification refers to the wall thickness. The outside diameter remains the same throughout the various weight classifications for any given pipe size.

(2) Standard pipe sizes come in random lengths of from 12 to 22 feet. Each section may be supplied with one coupling. Standard-weight pipe is the most common weight used in domestic-type installations. The heavier weights, extra-heavy and double-extra heavy, with sizes up to 8 inches in diameter, are used in both industrial and military TO installations. Galvanized-steel pipe is most commonly used for water-distribution systems within the walls of a building.

b. Copper and brass pipes. Copper and brass pipes in various weights and lengths are normally used in cold-storage installations and in places where temperatures and certain chemical conditions are critical.

c. Cast-iron pipe. Cast-iron pipe, which is manufactured in 12-foot lengths primarily for use as drainage pipe in plumbing systems, is not available for overseas shipment.

d. Joints. The use of bell-and-spigot joints is common in plumbing work. The type of pipe does not require such accurate cutting and fitting as threaded pipe, but more skill is required in making joints. Threaded joints are neater in appearance and can be installed

more quickly than bell-and-spigot joints. Drainage pipe with bell-and-spigot ends is jointed by calking with oakum and lead, or cement. Cementing of joints is common practice in underground drainage and waste systems.

e. Fittings. Figures 5-16 through 5-20 show some of the more common fittings. The fittings in figure 5-16 have been joined together to emphasize the different connections. Table 5-8 is an explanation of the fittings shown in figure 5-16. Figure 5-21 shows additional details of some of the fittings used in water-supply systems, together with brief descriptions of their functions.

f. Symbols. Symbols used in piping drawings vary. The most common are shown in figure 5-22. Study the symbols carefully.

g. Fixtures. The more common fixtures used in plumbing installations include sinks, lavatories, showers, water closets, urinals (fig 5-7), and drinking fountains.

h. Codes. Plumbing codes are set up by state and local governments to insure that safe and sanitary standards for plumbing are maintained.

5-10. PLUMBING LAYOUT

A plan drawing for a company bathhouse is shown in figure 5-23. This drawing gives details with respect to plumbing layout.

5-11. PREPARING A BILL OF MATERIALS

a. Table 5-9 is a bill of materials for the plumbing requirements for the company bath-house in figure 5-23. To prepare a bill of materials, each item on the drawing is checked, listed by name, and recorded by its stock number and size. A definite starting point and procedure is used for each group of materials. The cold-water lines are traced, for example, beginning at the source, and each item in the line is checked and recorded. Then the hot-water lines are traced and all items checked, and recorded in the same way. Always select a starting point, and then proceed along the line, checking off each item as it is recorded.

b. For example, tracing the cold-water lines on figure 5-23 from the source to the

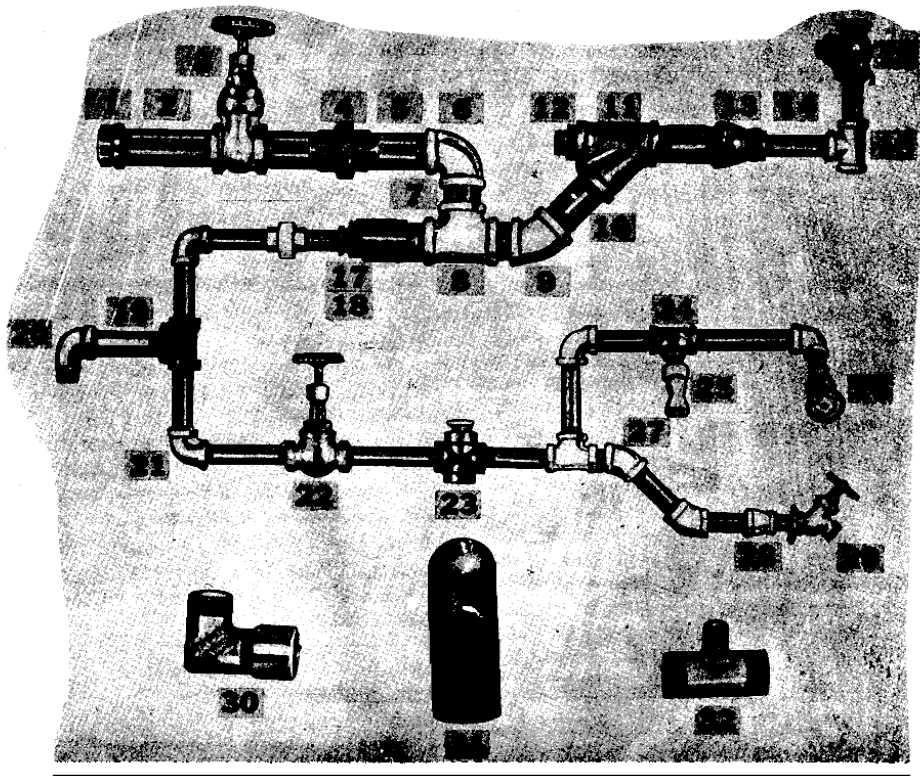


Figure 5-16. Pipe fittings and connections.

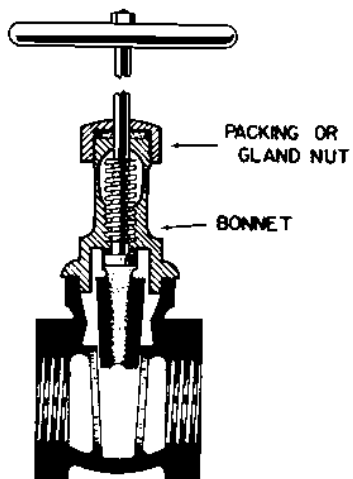


Figure 5-17. Gate valve.

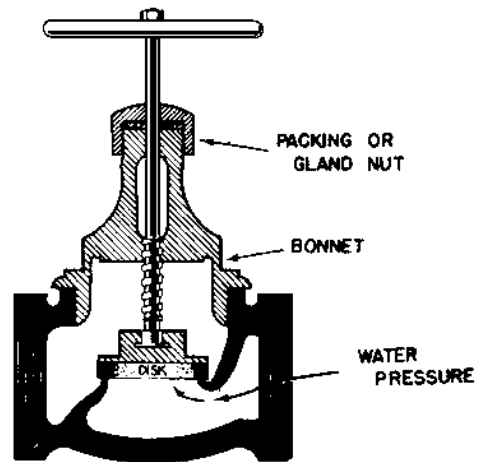


Figure 5-18. Globe valve.

TABLE 5-8. Explanation of Fittings in Figure 5-16

Item	Nomenclature	Description and use
1	cap	A cap has female threads and closes off the end of a male-threaded pipe or fitting.
2	nipple, long	A long nipple is usually a 5- to 8-inch length of pipe which is threaded on each end. It is used for short runs, stubbing-in fixtures, and for connecting two female-threaded fittings together.
3	valve, gate	A gate valve is used to open and close water mains and laterals. Figure 5-17 shows a cutaway view of a gate valve.
4	union	A union is used to connect two straight, fixed sections of pipe. Figure 5-19 shows a cutaway view of a union.
5	nipple, short	A short nipple is a length of pipe, generally 2 to 3 inches long, which is threaded on each end. It is used for stubbing-in fixtures, and for connecting two female-threaded fittings together.
6	elbow, standard 90-degree	This particular elbow has two female threads of the same size. The elbow is used to make turns in piping.
7	nipple, close	A close nipple is a piece of pipe under 2 inches in length. It has a continuous thread, but is threaded from both ends because of the taper in pipe threads. A close nipple must be cut with the use of a nipple chuck. Close nipples are usually cut in the factory. They are used for stubbing-in fixtures and for connecting two female-threaded fittings together.
8	tee, straight 1½-inch	Fitting No. 8 is listed as a 1½-inch straight tee. When ordering tee fittings, the main line of flow is always listed first and the tee-branch size last. For example, a tee installed in a 2-inch main line, with a 1-inch branch running off, is listed as a 2- by 2- by 1-inch fitting. Tees are used to connect branches to continuous lines.
9	elbow, standard 45-degree	This elbow is used to make gradual turns in piping.
10	nipple, short	Same as item 5.
11	Y-branch	The Y-branch is threaded and made of malleable iron. It is used to connect a branch line to a main at either a 45°, 60°, or 90° angle.
12	plug	This plug has male threads and is used to close a female, or inside-threaded, opening.
13	reducer	Reducing couplings have female threads. When ordering, state the correct name and size of the desired fitting. A reducing coupling is used to reduce pipe where ample space is available.
14	nipple, long	Same as item 2.
15	tee, standard	Same as item 8.
16	valve, check	A valve which allows flow in one direction only.
17	bushing	The bushing has a male and female thread. Do not confuse the bushing with the reducer (item 13). The reducer has only female threads. A bushing is used for reducing pipe size.
18	bushing	Same as item 17.
19	tee, increasing	This tee is listed as ¾-inch by ¾-inch by 1-inch. It is used to connect a larger line perpendicular to a smaller line.
20	elbow, street	This elbow has inside threads on one end and outside threads on the other. Often called street ell.
21	elbow, standard 90-degree	Same as item 6.
22	valve, globe	The globe valve is used for adjusting the flow of water. It is used frequently on shower lines to adjust the flow of hot and cold water. Figure 5-18 shows a cutaway view of a globe valve.

TABLE 5-8. Continued

Item	Nomenclature	Description and use
23	cross	A cross is frequently inserted in a main line at points where branches may be required in future expansion of the area. In this case, the branches are plugged until needed.
24	tee, reducing	A reducing tee is used to connect a smaller line perpendicular to a larger line. This particular tee is listed as 3/4-inch by 3/4-inch by 1/2-inch. Figure 5-20 shows a reducing tee.
25	shower head, fixed	This item has a fixed head with a straight fixed shank.
26	shower head, adjustable	This item has an adjustable head with a built-in ball-and-socket.
27	elbow, 45-degree	Same as item 9.
28	reducer	Same as item 13.
29	faucet, hose-bibb	This item is a threaded-faucet outlet to which hoses may be attached. The faucet itself has female threads and a flange, but the bibb has male threads. It is also known as a sill cock.
30 31 32	field expedients for elbows, caps, and tees, respectively	The construction of these fittings and many others is common in both military and civilian installations. The use of welding in pipe work is now an established and recognized method in both military and civilian construction.

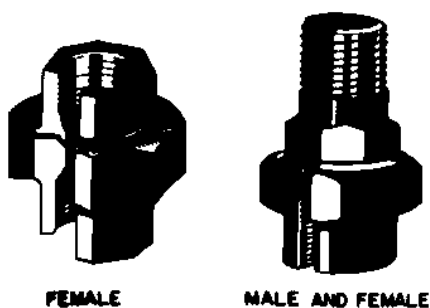


TABLE 5-19. Cutaway view of a union.

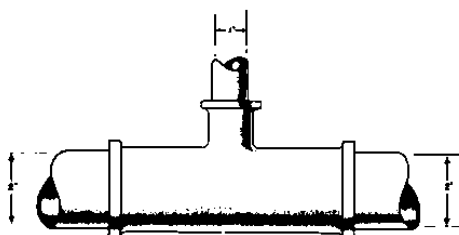


Figure 5-20. Reducing tee.

hot-water heater and to the fixtures and other outlets shows that the fittings required are as follows:

Item	Size	Number required
(a) gate valve	2"	1
(b) angle gate valve	2"	1
(c) tee	2" x 2" x 3/4"	3
etc		

c. Again, tracing the hot-water lines from the storage tank to the fixtures and other outlets, the fittings required would be itemized as follows:

Item	Size	Number required
(a) elbow (90°)	2"	1
(b) angle gate valve	2"	1
etc		

d. After tracing all lines and determining the kinds and number of fittings in each branch, consolidate the figures into one bill of materials similar to the one in table 5-9.

e. To conserve critical materials, certain military construction items may be substituted for others in short

supply. For example, reducing couplings and bushings may be substituted when reducing fittings are not available.

5-12. MEASURING PIPE LENGTHS

Threaded pipe may be measured in any one or any combination of several methods. It is important to know which method is being used in any given measurement and to allow for fitting dimensions (end-to-end or end-to-center) and for length of thread engagement (table 5-10).

a. **End-to-end measure.** End-to-end measure (1, fig 5-24) is the full length of the pipe including both threads.

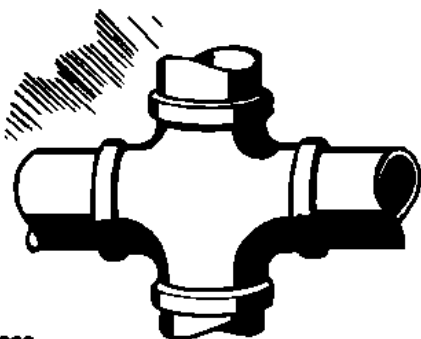
b. **End-to-center measure.** End-to-center measure (2, fig 5-24) is used for a piece of pipe having a fitting screwed on one end only. The pipe length is equal to the measurement minus the end-to-center dimension of the fitting plus the length of thread engagement.

c. **Face-to-end measure.** Face-to-end measure (2, fig 5-24) is also used for a piece of pipe having a fitting screwed on one end only. In this case the pipe length is equal to the measurement plus the length of thread engagement.

d. **Center-to-center measure.** Center-to-center measure (3, fig 5-24) is used for a length of pipe which has a fitting screwed on both ends. The pipe length is equal to the measurement minus the sum of the end-to-center dimensions of the fittings plus two times the length of thread engagement.

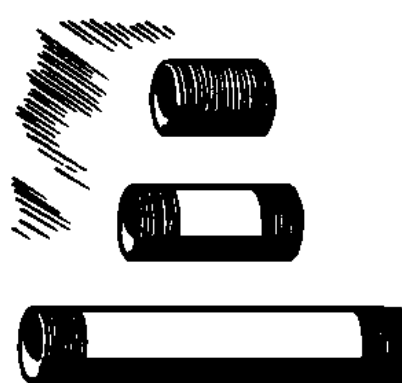
e. **Face-to-face measure.** Face-to-face measure (3, fig 5-24) is used under the same circumstances as in d above. The pipe length is equal to the measurement plus two times the length of thread engagement.

f. **Measuring offsets.** When it is necessary to run an offset with threaded pipe, use Figure 5-25 and the following procedure. For example, assume that a 45° offset with a 3-inch pipe is to be measured, and the distance between the parallel runs A (center-to-center of pipe) is 40 inches. Then, from



Cross

Connects two branch lines to a continuous line.



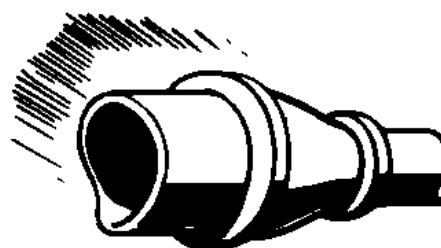
Nipples

Used for short runs and for stubbing-in fixtures.



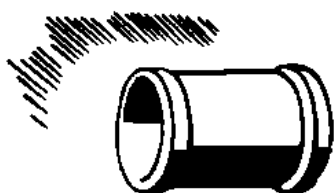
Y-branch

Connects a branch at 30°, 45°, 60° or 90° to a continuous line.



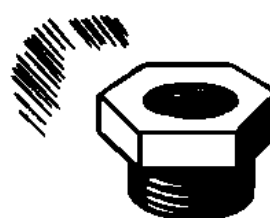
Reducer

Joins two sections of pipe of different sizes.



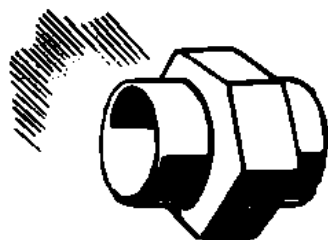
Coupling

Connect straight sections of pipe.



Bushing

Used to reduce an outlet in a fitting or to connect a pipe to a larger outlet.



Union

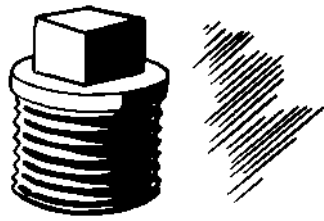
Joins two straight, fixed sections of pipe. Unions can be uncoupled without tearing down the installed pipework.



Cap

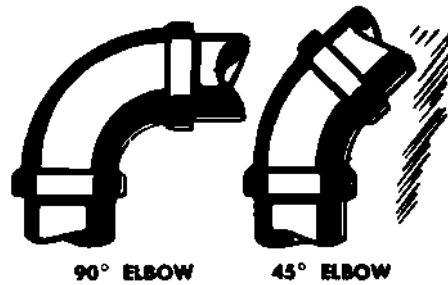
Closes the end of a pipe with outside threading.

Figure 5-21. Fittings for water-supply systems.



Plug

Used in place of cap where pipe has inside threads.

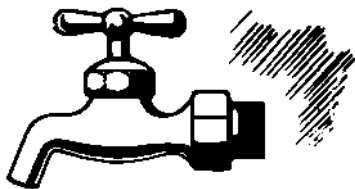


90° ELBOW

45° ELBOW

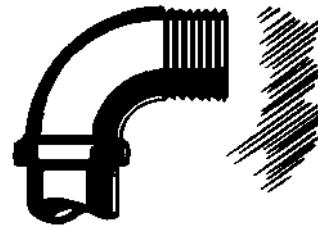
Elbows

Used to make turns in piping. Often called ells.



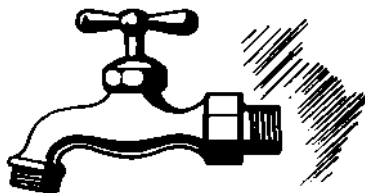
Plain-bibb Faucet

Controls water flow at an outlet.



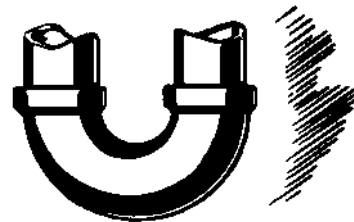
Street Elbows

Used on inside and outside thread joints. Often called street ells.



Hose-bibb Faucet

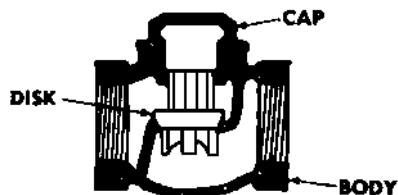
A threaded faucet outlet to which hoses may be attached.



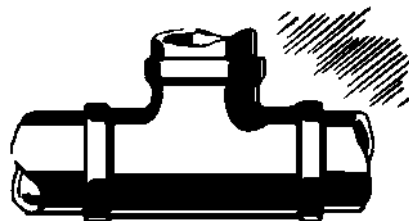
Return Bend

Used to make a 180° turn.

VALVES



Check valves are used in water mains and on the suction side of pumps to prevent water from draining out of the pipes.



Tees

Used to connect branches to continuous lines.

Figure 5-21. Continued

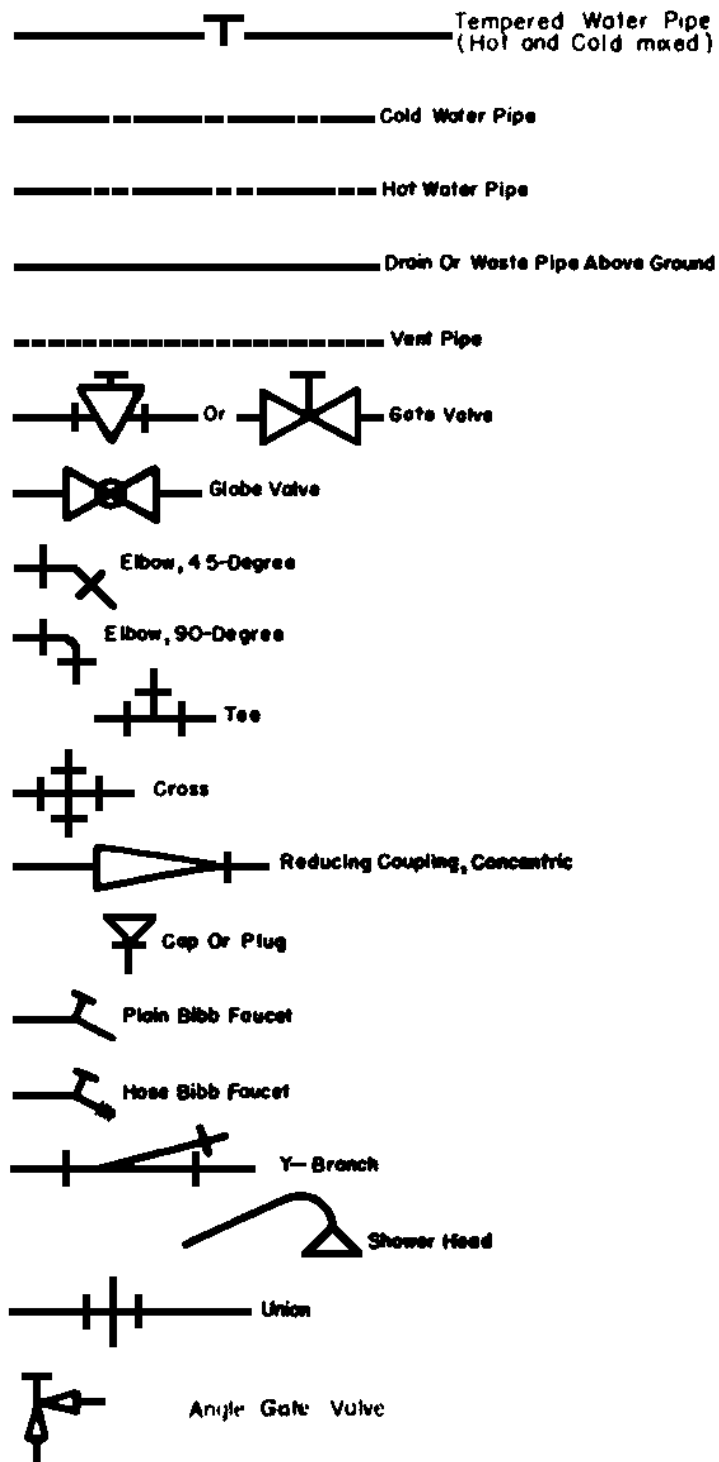


Figure 5-22. Plumbing symbols.

TABLE 5-9. Bill of Materials for Company Bathhouse

ITEM NO.	ITEM	S.N.L. STOCK NO.	UNIT	BATH- HOUSE ALL CLI- MATES
	PLUMBING			
	BUSHING, pipe, iron, cast, FS WW-P-501, 125 pressure, Type A, reducing, threaded, black, Class 1, inside head: 2" x ¾"	45-1753.02-007	EA	3
	4" x 2"	45-1753.04-02	EA	1
	CROSS, pipe, iron, malleable, 150 lb. pressure, FS WW-P-521, threaded, straight, black, Class A: ¾"	45-2988.3-007	EA	4
	ELBOW, drainage, FS WW-P-491, iron cast, black:			
	Long turn, 90 degree; 2"	45-3408.9-02	EA	1
	Short turn, 45 degree; 2"	45-3436.45-02	EA	—
	ELBOW, pipe, iron, cast, 125 lb. pressure, straight, threaded, FS WW-P-501, 90 degree, black, Class 1: 2"	45-3632.9-02	EA	18
	ELBOW, pipe, iron, malleable, 150 lb. pressure, FS WW-P-521, 90 degree, black, Class A:			
	straight, ¾"	45-3716.93-007	EA	2
	street, reducing, threaded; ¾" x ½"	45-3744.007-005	EA	6
	FAUCET, iron, cast, brass trimmed, compression, hexagon shoulder, T handle:			
	hose bibb; ¾"	45-4156.3-007	EA	1
	plain bibb; ¾"	45-4156.5-007	EA	6
	NIPPLE, pipe, FS WW-N-351, steel, standard, Type A, black:			
	IPS LENGTH			
	¾"	2"	45-5750.007-02	EA 2
	¾"	4"	45-5750.007-04	EA 2
	¾"	6"	45-5750.007-06	EA 2
	2"	2½"	45-5750.02-025	EA 5
	2"	4"	45-5750.02-04	EA 10
	2"	6"	45-5750.02-06	EA 7
	4"	4"	45-5750.04-04	EA 2
	4"	6"	45-5750.04-06	EA 2
	4"	8"	45-5750.04-08	EA 2
	½"	1½"	45-5750.005-015	EA 8
	PLUG, pipe, iron, cast, 125 lb. pressure, FS WW-P-501, threaded, square head, black, Class 1: 2"	45-6040.5-02	EA	2
	TEE, pipe, iron, cast, FS WW-P-501, 125 lb. pressure, Type A, threaded, black, Class 1:			
	reducing; 2" x 2" x ¾"	45-7435.02-007	EA	1
	straight; 2"	45-7570.05-02	EA	4
	TEE, pipe, iron, malleable, 150 lb. pressure, FS WW-P-521, straight, threaded, black, Class A: ¾"	45-7725.05-007	EA	3
	TRAP, drainage, iron cast, threaded, black:			
	"P", 2"	45-8196.06-02	EA	1
	4"	45-8196.06-04	EA	2
	UNION, pipe, iron, malleable, 125 lb. pressure, threaded, ground joint, iron seat, black: 2"	45-8395.4-02	EA	6
	VALVE, iron, cast, 125 lb. pressure, threaded, gate, FS WW-V-76, brass trimmed, inside screw, rising stem, 2"	45-8840.5-02	EA	4
	Y-drainage, iron, cast, threaded, 90 degree, long turn, tee pattern: straight, single; 2"	45-9250.02-02	EA	1
	Y-drainage, iron, cast, threaded, 45 degree:			
	Straight, single; 2"	45-9264.1-02	EA	2
	4"	45-9264.1-04	EA	2

TABLE 5-9. Continued

ITEM NO.	ITEM	S.N.L. STOCK NO.	UNIT	BATH-HOUSE ALL CLIMATES
	<u>PLUMBING</u>			
	COMPOUND, pipe, joint and thread lubricant, for steam and water pipes, 1 lb. can	52-2759.5-5	LB	3
	OIL, cutting, mineral, lard, FS VV-0-251, grade 2, 1 gal. can	14-6005.2-01	GA	½
	TANK, storage, steel, hot water, welded, black, w/6 2" connections: 330 gal. 575 gal.	60-8480.36-033 60-8480.42-057	EA EA	1 --
	HEATER, water, steel, ES T-1884, force draft, motor driven, liquid fuel, Type VI: 600 GPH — 250,000 BTU PH 2000 GPH — 830,000 BTU PH	60-6043.84-06 60-6043.84-2	EA EA	1
	SHOWER HEAD, iron, galvanized, non-clogging, with ball joint inlet, ½", Crane No. CE-4871 or equal	30-6500.5-5	EA	8
	VALVE, shower, self-closing, iron body, brass trimmed, ½", with chain and pull ring, Federal Huber, Fig. 19805 or equal	30-9000.3-5	EA	8
	DRAIN, shower, and wash bench, with 2" IPS outlet 4" IPS outlet	30-3050.2-6 30-3050.4-9	EA EA	1 2
	PIPE, steel, seamless or welded, FS WW-P-403, black, standard, Class A, threaded with couplings: ¾" 2" 4"	44-6246.7-007 44-6246.7-02 44-6246.7-04	FT FT FT	30 110 10
	CROSS, pipe, iron, cast, 125 lb. pressure, FS WW-P-501, black, Type A: 2"	45-2932.5-02	EA	--
	VALVE, thermostatic, water mixing, ES T-2072, 2"	45-9155.5-02	EA	1

TABLE 5-10. Pipe-Thread Data for Standard Pipe

Size of pipe (inches)	Outside diameter (inches)	Number of threads per inch	Total length of threads (inches) (approx.)	Effective length (inches) (approx.)	Thread engagement (inches) (approx.)
1/4	.54	18	5/8	3/8	3/8
3/8	.675	18	5/8	7/16	3/8
1/2	.840	14	13/16	9/16	1/2
3/4	1.05	14	13/16	9/16	1/2
1	1.315	11 1/2	1	11/16	9/16
1 1/4	1.660	11 1/2	1	11/16	5/8
1 1/2	1.9	11 1/2	1	3/4	5/8
2	2.375	11 1/2	1 1/16	3/4	11/16
2 1/2	2.875	8	1 9/16	1 1/8	15/16
3	3.5	8	1 5/8	1 3/16	1
4	4.5	8	1 3/4	1 5/16	1 1/16
5	5.560	8	1 13/16	1 3/8	1 3/16
6	6.625	8	1 15/16	1 1/2	1 1/4

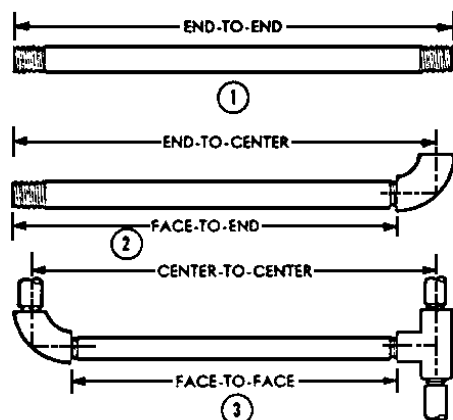
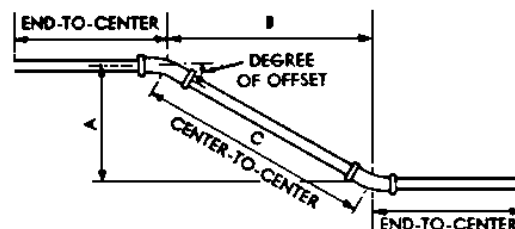


Figure 5-24. Threaded pipe measurements.

figure 5-25, distance C (center-to-center of the 45° elbows) is 40 times 1.4142, or approximately 56.57 inches. A standard 3-inch 45° elbow (125 lb. cast iron or 150 lb. malleable, screw type) is 2.17 inches end-to-center, and from table 5-10, requires a 1-inch thread engagement. Deduct 4.34 inches (2 x 2.17) and add 2 inches for two thread engagements which results in an end-to-end length of pipe of 54.23, or 54 1/4 inches. Table 5-11 gives end-to-center dimensions for 90° and 45° screw type elbows of 125 lb. cast iron and 150lb. malleable metal having nominal diameters ranging from 1/4 inch to 6 inches. End-to-center dimensions for elbows of other type, size, and degree of bend may be found in any good pipefitters handbook, or may be measured in the field. The center of the elbow for this purpose is considered to be at the point of intersection of the centerlines of the two straight runs of pipe being connected.

g. Copper tubing. Copper tubing is measured in the same way as threaded pipe. Allowance is made for fitting dimensions (solder or compression type) and for the distance the tubing is inserted into the fitting. Offsets for rigid type tubing are calculated in the same manner as for threaded pipe. It is generally unnecessary to use fittings for offsets with flexible tubing since this type is easily bent.



DEGREE OF OFFSET	WHEN A = 1, B =	WHEN B = 1, A =	WHEN A = 1, C =
60°	0.5773	1.732	1.1547
45°	1.000	1.000	1.4142
30°	1.732	0.5773	2.0000
22 1/2°	2.414	0.4142	2.6131
11 1/4°	5.027	0.1989	5.1258
5 1/2°	10.168	0.0983	10.217

Figure 5-25. Pipe measurement for offset.

5-13. VALVE PROTECTION

- a. Use wrench on hex head near joint to prevent damage to valve.
- b. Install valve in closed position. Chances of damage to working parts will be minimized.
- c. Support pipe on either side of valve to relieve strain on the valve.
- d. Thread pipe to standard length, so pipe will tighten before striking valve seat.
- e. Put joint compound on pipe threads, not on valve threads.
- f. Use short wrenches to repair valves. A few taps with a hammer are better than a heavy, constant, twisting pull.
- g. Consult maintenance manuals for repair procedures to avoid damaging valves.
- h. Open valves part way to flush out foreign matter in the seat. Open valve wide, then turn back one-quarter turn to prevent jamming. Never close valve with one fast turn, as this will cause water to hammer on valve.
- i. Use globe valves for throttling fast flows. A full flow around seat will balance disk support in valve.
- j. Install automatic check valves in an upright position.

Table 5-11. Center-to-End Dimensions for 90° and 45° Screw-Type Elbows (125 lb. Cast Iron and 150 lb. Malleable)

Nominal Diameter (in.)	Center-to-End (90°)	Center-to-End (45°)
1/4	0.81	0.73
3/8	0.95	0.80
1/2	1.12	0.88
3/4	1.31	0.98
1	1.50	1.12
1 1/4	1.75	1.29
1 1/2	1.94	1.43
2	2.25	1.68
2 1/2	2.70	1.95
3	3.08	2.17
3 1/2	3.42	2.39
4	3.79	2.61
5	4.50	3.05
6	5.13	3.46

5-14. SINGLE SHOWER

Install hot- and cold-water lines on shower wall and globe valves in each line. Connect long nipple and a 90° bend to each valve. Then, connect two long nipples by a union to a tee and connect the cold-water line to the tee. Install tempered-water pipe in tee and install the quarter bend, pipe, 3/4 by 1/2-inch street elbow, and shower head so shower head is 1 foot 6 inches from wall line and 5 feet 9 inches to 6 feet 1 inch above floor (fig 5-26).

5-15. GROUP OF SHOWERS

The hot- and cold-water lines are connected to the tempered-water line in the same way as described for the single shower. Connect each shower head to the tempered-water line with a tee. The shower head is attached to a short nipple, chain valve, and a street elbow. Each shower head has a ball joint used to vary direction of water flow.

5-16. WATER HEATER WITH VERTICAL WATER TANK

Installation of the vertical tank varies from the horizontal tank installation only in the

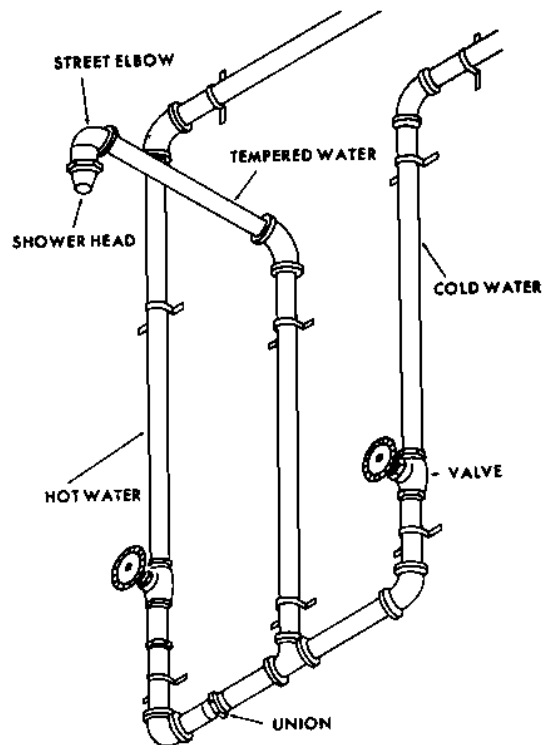


Figure 5-26. Typical exposed shower piping.

position of the tank. The drain pipe is connected with a tank nipple.

5-17. WATER HEATER WITH RANGE BOILER

This heater and boiler are installed similarly to the vertical and horizontal storage tank and heater. Cold-water supply pipe is installed in the tank using a circulator-boiler fitting. Bottom end of cold-water pipe should open into range boiler approximately 8 inches from bottom of boiler (fig 5-27).

5-18. SAFETY RULES

Plumbing is not a hazardous trade, if the plumber and his assistants are careful. By observing and enforcing a few simple safety rules, time loss due to accidents can be cut to a minimum. Pick up scrap pieces of pipe. Keep all tools and materials not in use off the job. Keep floors dry, cover oily floors with sand.

a. Stockpiling materials.

Stockpile materials far enough from job so they do not interfere with installation. Stack materials straight; brace and block stockpiles carefully to prevent them from falling.

b. Maintenance of tools. Keep tools in good condition. Replace all worn tools. Loose wrench jaws may cause a bad fall or broken knuckles. Check hammer handles frequently. Never use hammers with broken or cracked handles.

c. Blowtorch and hot lead.

Careless handling of hot lead and blowtorches may result in serious burns. When pouring hot lead, wear heavy, protective clothing; do not bring hot lead near inflammable materials; and keep out from under hot-lead joints while they are being poured.

d. Protective clothing. Cut and bruised fingers and hands can be avoided by wearing heavy gloves when handling pipe. Heavy coveralls and shoes and leggings will protect the plumber from hot lead.

e. Ladders. Ladders must be strongly constructed and in good repair. When using a ladder, the base must be held firmly by an assistant, the siderails must be buried 4 or 5 inches in the ground or supported by a block nailed to the floor, or the base must be held in position by a rope. The base of the ladder should be placed one-quarter of the length of the ladder from the wall.

f. Scaffolds. Serious accidents may result if scaffolds are not well-built and securely anchored. Select scaffold planks and bracing carefully. They should be free of knots, checks, and cross-grained sections. To test scaffold planks, block each plank 1 foot off the ground and load it with three times the weight it must support. At the least sign of weakness, the plank should be discarded.

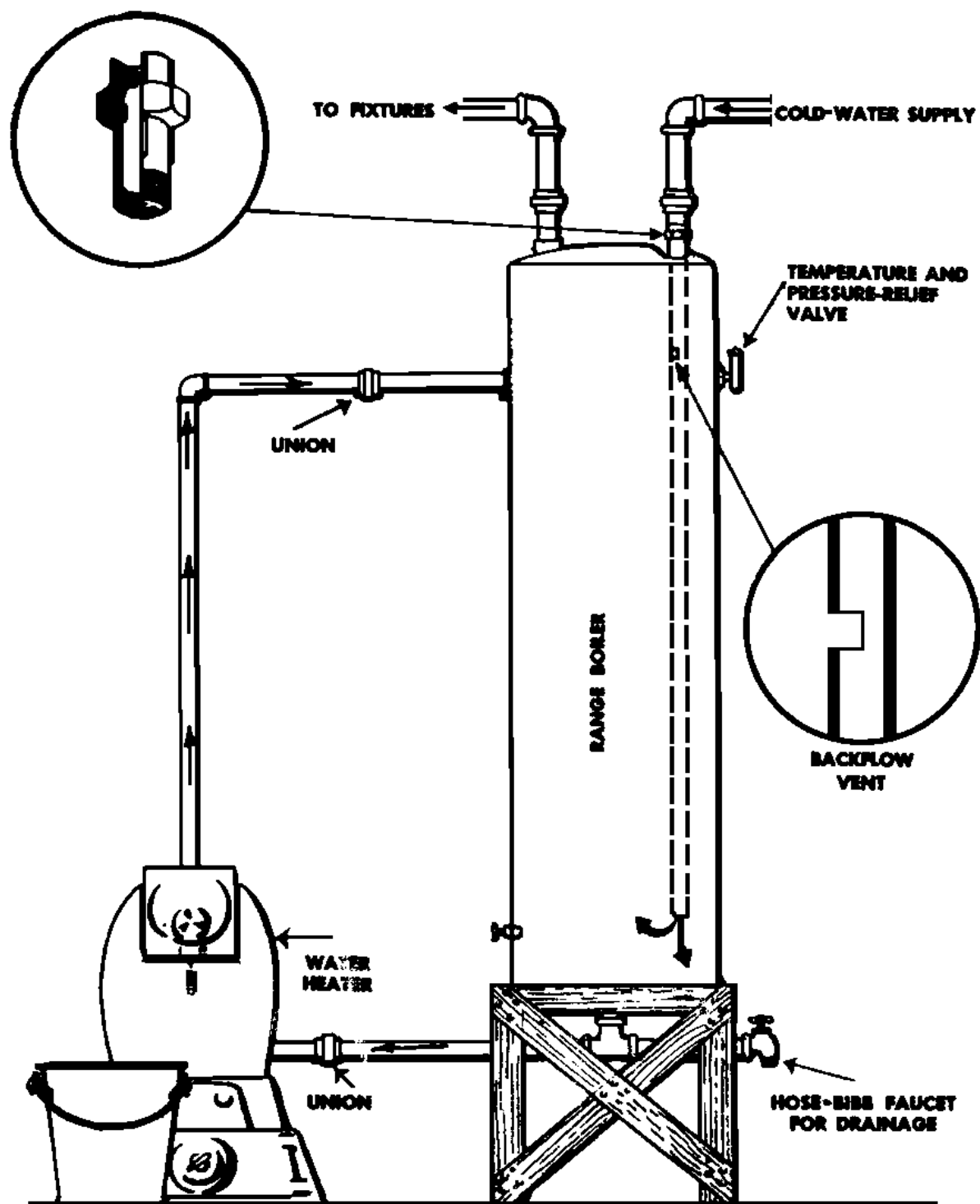


Figure 5-27. Water heater and range boiler.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each question refer to a paragraph containing information related to the question. Write your answer in the space provided below each question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in the back of this booklet. Review the lesson as necessary. Do not send in your solutions to these review exercises.

1. The plumbing system in a building has two purposes, one is to supply water to various parts of the building. What is the other? (Para 5-1b)

2. In the waste system where does the building drain connect to the building sewer? (Para 5-1e(8)(4))

3. What is the name of the fitting that prevents sewer gases and odors from backing up through fixtures? (Para 5-1e(14))

4. In the design of a plumbing system why is it desirable to keep bends and fittings to a minimum? (Para 5-2c)

5. What documents are essential to making an accurate estimate of the amount of pipe required for any plumbing installation? (Para 5-3b, fig 5-10)

6. In the design of a plumbing layout for a temporary installation, what can you do to reduce the amount of piping and fixtures required for showers and lavatories? (Para 5-3c, fig 5-10)

7. Assuming availability of pipe sizes is not a problem, what are the two most important factors in sizing a water service? (Para 5-4a)

8. Determine the maximum fixture demand for a plumbing installation which will include four urinals, two water closets, two slop sinks, three shower stalls, one laundry tray, and six lavatories. (Para 5-4a(2), table 5-2)

9. While many factors must be considered in determining pipe size, there is a minimum size specified for the water service line. What is this minimum size specified? (Para 5-4a(4))

10. Why is it undesirable to design hot water systems with dead ends? (Para 5-5d)

11. All wastes from a building drain system pass through the building sewer to the street sewer. What is a peculiarity of the drain-plan of a scullery sink? (Para 5-6b)

12. Why is it necessary that vents be installed in conjunction with traps in waste lines? (Para 5-7d)

13. You are designing a bathhouse to serve a maximum of 250 troops in a theater of operations. What will be the minimum hot-water storage requirements in gallons for this bathhouse? (Para 5-8e)

14. Bell-and-spigot joints are used commonly in plumbing work. What advantage does this type joint have over threaded joints? (Para 5-9d)

15. Explain the best procedure to follow in preparing a bill of materials, to insure that no items are overlooked. (Para 5-11a)

16. State the procedure you would follow in determining the length of pipe to cut in an offset situation, with threaded pipe. (Para 5-12f)

17. In a plumbing system, what type of valve is used for throttling fast flowing water? (Para 5-13i)

18. In the installation of a water heater with range boiler, where should the cold water supply pipe open into the boiler? (Para 5-17)

19. When stockpiling materials at a plumbing job site, what should you consider from the safety standpoint? (Para 5-18a)

20. To be in its safest position, how do you place a ladder against a wall? (Para 5-18e)

LESSON 6

SEWERAGE SYSTEMS

CREDIT HOURS	3
TEXT ASSIGNMENT.	Attached memorandum.
MATERIALS REQUIRED	None.
LESSON OBJECTIVE	Upon completion of this lesson on sewerage systems you should be able to accomplish the following in the indicated topic areas.

- 1. Characteristics of sewerage systems.** Define the characteristics and estimate the quantities of sewage that will be produced by a military installation.
- 2. Methods of disposal.** Explain the methods of sewage treatment and disposal most commonly used at military establishments, including dilution, primary and secondary treatment, and chlorination.
- 3. Cesspools and septic tanks.** State the characteristics and the differences between cesspools and septic tanks.
- 4. Planning and design.** Developed a basic plan for a sewage disposal system based upon known requirements and criteria. From the basic plan, complete a detailed design of a sewage disposal system.
- 5. Operation and maintenance.** Outline all steps and procedures to be followed in operation and maintenance of the sewage disposal plant.

ATTACHED MEMORANDUM

6-1. INTRODUCTION

Personnel responsible for the planning, design, construction, operation, and maintenance of sewerage systems must be familiar with the characteristics and quantities of sewage from military establishments and the methods of disposal and treatment of the sewage, including dilution, primary and secondary treatment, and chlorination.

a. Sewage. Sewage is the liquid waste from latrines, showers, wash trays, and kitchens. Sewage collected in a pipe system may contain ground and surface runoff waters, although they are excluded from sewerage systems in military installations as

far as possible. Waste water containing oil or gasoline generally should be excluded from the sewerage system, since petroleum products in sewage make treatment difficult and petroleum vapors create an explosion hazard in manholes and pipes. If the volume of such waste is small and other means of disposing of it are not practical, a combined sand and grease trap may be used to clean the petroleum-contaminated water before it enters the sewer system.

b. Collections. Sewage collection pipes are called sewers and, depending on their function or location, may be termed house-connection, lateral, branch, main or trunk,

bypass, or outfall sewers (fig 6-1). Relief sewers generally parallel and relieve excessive loads on existing lines.

c. Disposal. Sewage must be disposed of because it endangers health. In populated areas, the method used also should eliminate offensive appearance and odor. Untreated sewage can be discharged

into bodies of water if dilution is such that no nuisance health hazard is created. The effluent from treatment plants may be disposed of similarly or may percolate into the soil through irrigation and leaching systems. Treated sewage also may be evaporated into the air from surface irrigation systems and oxidation ponds.

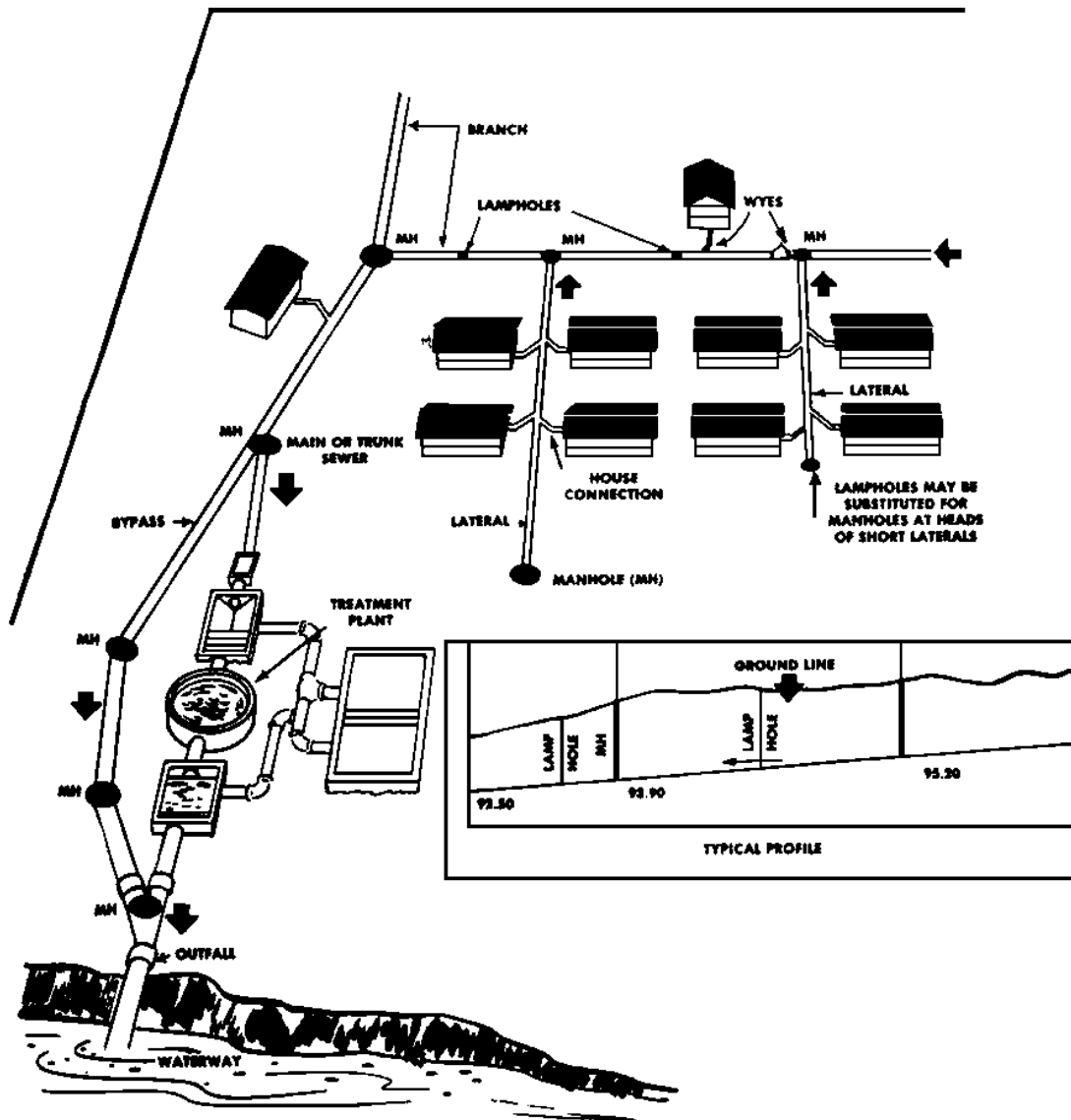


Figure 6-1. Layout, plan and profile, and nomenclature of sewers.

d. Treatment. Where dilution is insufficient to safeguard health, raw sewage must be treated to eliminate offensive conditions in the receiving stream or body of water or to permit later use of the diluting water.

6-2. CHARACTERISTICS

a. Content. Waterborne sewage is 99.8 percent or more water. The remaining offensive matter is mostly organic and consists of finely divided particles in suspension and solution about 50 to 60 percent of the suspended solids and 35 percent of all unstable matter, measured in terms of its biochemical oxygen demand, can be removed by settling in properly designed tanks. Biochemical oxygen demand, (BOD) is the amount of oxygen which is required for stabilization of the decomposable organic matter through biological action. The BOD remaining after primary settling can, be removed by the biological processes that take place in trickling or sand filters or in oxidation ponds and other bodies of water. However, the BOD is normally not reduced to zero in the facilities.

b. Strength. The strength of sewage is measured by the amount of suspended solids and by the amount of biochemical oxygen demand. BOD is usually measured as oxygen demand in pounds per million pounds of sewage over a 5-day period at 20°C. Sewage strength varies with the amount of water used. The following figures are average amounts of suspended solids and BOD for theater of operations installations:

Item	1,000 people
	25,000 to 50,000
Sewage flow _____	gallons/day
Suspended solids	
(dry weight) _____	270 pounds/day
BOD (5 days at 20°C) _____	200 pounds/day

6-3. QUANTITIES

The quantity of sewage that must be disposed of varies with the number of troops in the camp and the restrictions placed on the use of water. Flows generally range between 15 and 50 gallons per capita per day (gcd), although permanent installations with

ample water supplies may use more. For airfields, cantonments, and the like the average flow varies from 25 to 50 gcd and for hospitals from 50 to 85 gcd. This figure includes sewage of all medical personnel. Examples and designs in this lesson are based on 25 gcd, and must be varied if sewage quantity estimates are changed.

6-4. DILUTION

a. Stream flow required.

(1) Stream flow required for disposal of sewage by dilution depends on the strength and quantity of the sewage, the density and nearness of population to the streambank, and the industrial or domestic use of the stream water below the outfall. A stream overloaded with sewage develops sludge banks and surface scum, is unsightly, and emits an offensive odor. Table 6-1 is a guide for determining the quantity of sewage that may be discharged into a stream, provided the stream water below the sewage outfall is not used for industrial and domestic water supply.

TABLE 6-1. Minimum Stream Flow Required for Dilution of Raw and Treated Sewage

Type of treatment	Dilution per 1,000 sewage-contributing population	
	Densely populated areas	Sparsely populated areas
None -----	20 cfs and over	5 cfs and over
Partial (settling) -----	12 to 20 cfs	3 to 5 cfs
Complete -----	6 to 12 cfs	0 to 3 cfs

* Oxidation ponds or irrigation with disposal to ground water can be used if enough water for dilution is not available.

(2) Military standards for dilution and sanitary conditions are the same as those used in civilian practice. If military expediency necessitates substandard sanitary conditions, they are corrected as rapidly as possible.

b. Disposal points.

(1) **Oceans and lakes.** Sewage outfalls (discharge points) in oceans and lakes should be located as far as possible from water supply intakes and swimming areas. Prevailing currents, tides, and winds also should be considered, so the sewage is carried away from the shore and intakes and swimming

areas. For best distribution, the outfall should enter the body of water at the deepest portion.

(2) Rivers and streams. The principles followed in locating outfalls in rivers and streams are the same as those for oceans and lakes. The discharge of the outfall should be in the swiftest part of the stream, not in the slack water close to shore. Where streamflow varies with the season of the year, it may be necessary to combine treatment with dilution during low summer flows.

6-5. TREATMENT

If treatment is required, the type of treatment and plant depends on the quantity of sewage, soil conditions, materials and labor available, and the climate. The Medical Department is responsible for determining the degree of treatment required before disposal. Treatment may be primary only or primary and secondary, depending on the conditions controlling the disposal methods.

a. Primary treatment. Primary treatment (fig 6-2) consist of separating suspended solids from the liquid sewage by settling, and stabilizing these solids by digestion, drying, or both (para 6-6b). Septic tanks, cesspools, Imhoff tanks, plain settling tanks, separate sludge digestion tanks, and sludge drying beds are used for various processes of primary treatment. The effluent from the tank is disposed of by dilution or

irrigation. The digested settled solids (sludge) in digestion tanks, Imhoff tanks, or septic tanks are removed periodically, usually by pipeline, to sludge drying beds.

b. Secondary treatment. Secondary treatment (fig 6-3) is accomplished by further treating the effluent after primary treatment to obtain a higher degree of purification. This does not produce a clear and potable water, but gives a product that can be discharged into streams or ground water without contaminating them enough to make their purification difficult. The secondary treatment of effluent is accomplished by one or more of the following methods:

- (1) Irrigation.
- (2) Oxidation ponds.
- (3) Trickling filters with final settling tanks.
- (4) Sand filters.
- (5) Leaching cesspools (a form of irrigation).

6-6. TREATMENT AND DISPOSAL OF SOLIDS

The following processes are used in the removal of solids:

a. Screening and settling. Large floating or suspended solids can be removed by a bar screen (fig 6-10). Primary settling tanks (figs 6-4 and 6-11) are used to settle out the settleable solids. The sludge is withdrawn from the tank bottom at frequent intervals, and digested in separate sludge digestion tanks (fig 6-4), and then conveyed to sludge

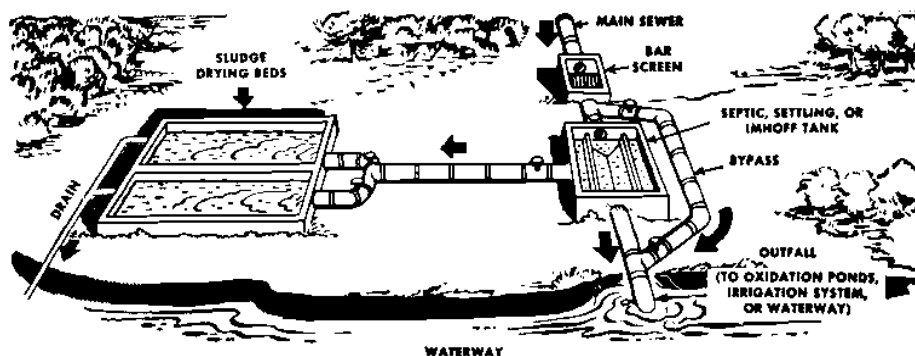


Figure 6-2. Primary treatment settling type plant.

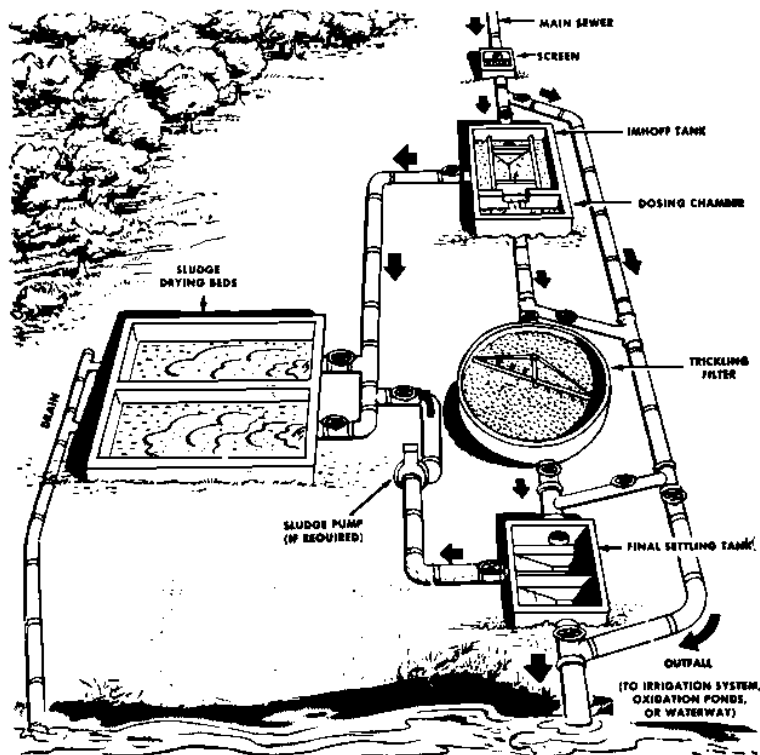


Figure 6-3. Primary and secondary treatment plant with Imhoff tank.

drying beds. However, in most military installations, preliminary screening and plain settlement are omitted and the raw sewage is discharged directly into a septic or Imhoff tank that combines settling with sludge digestion. The sludge from Imhoff and separate sludge digestion tanks contains about 95 percent water and is drawn off, following digestion, to the sludge drying beds. Sludge from septic tanks is difficult to dry on beds. It usually is pumped or bailed out, hauled from the site, and buried.

b. Digestion.

(1) Digestion is essentially a controlled rotting or putrefaction which changes the settled solids from a complex organic material to a stable and inoffensive earthlike material.

(2) The simplest type of digestion tank is an earth pit which can be used when odor control is not essential. When earth pits are used, they should be lined with concrete

unless the soil is impervious enough to maintain a satisfactory liquid level. Tanks constructed of concrete, steel, or wood are more common and are more satisfactory.

(3) Septic tanks, Imhoff tanks, and cesspools combine settlement and digestion and may be open or enclosed, as required by odor, fly nuisance, and temperature control.

(4) Following digestion, the moisture content of the sludge is reduced to about 65 percent by air-drying on porous beds (with or without underdrains). The dried sludge can be handled with a fork or shovel and used in fill or as fertilizer.

6-7. TREATMENT AND DISPOSAL OF LIQUIDS

The effluent from settling tanks (settled sewage) may be directly disposed of by dilution, irrigation, or evaporation and percolation; or may be further treated in oxida-

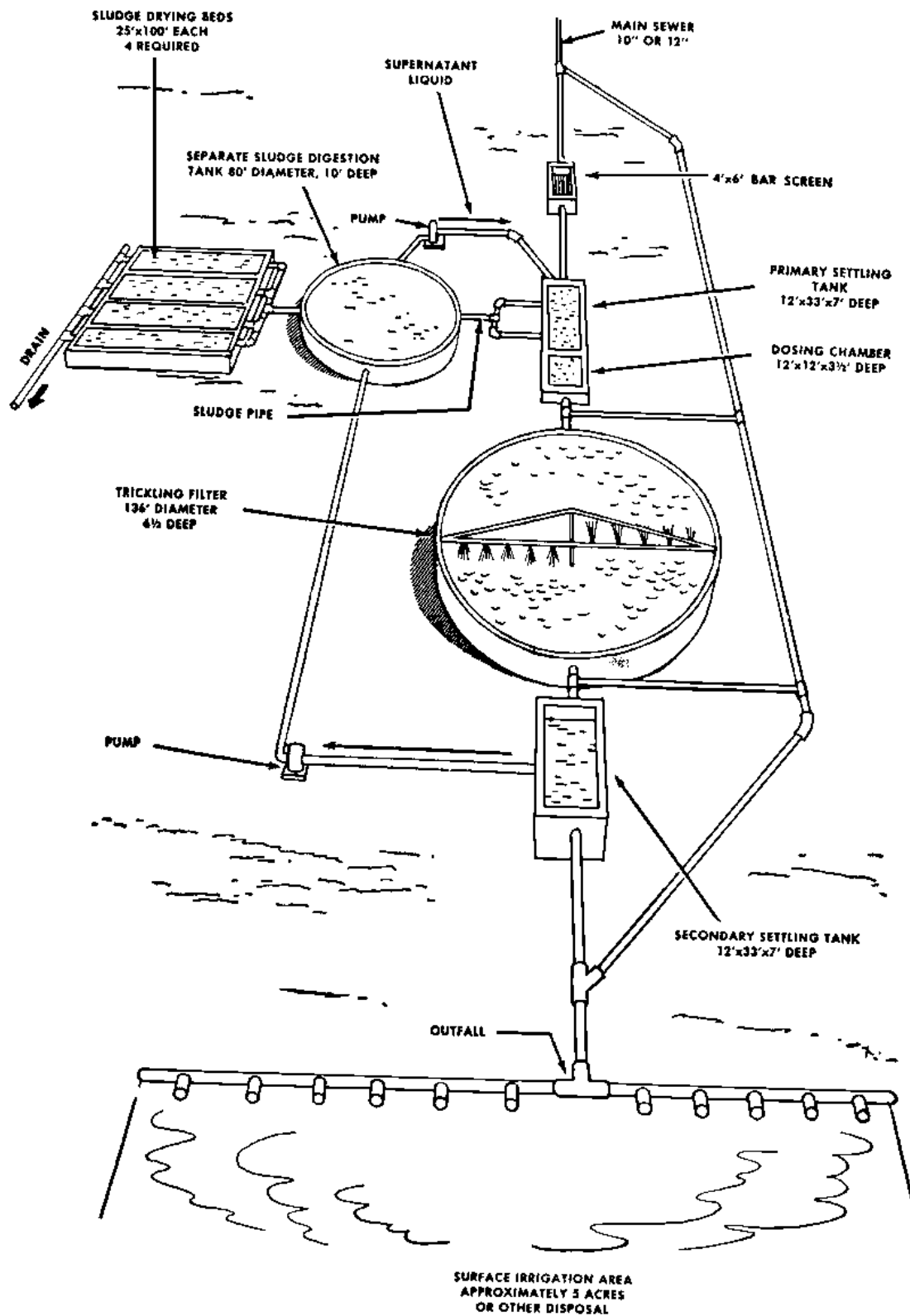


Figure 6-4. Complete treatment plant with separate sludge digestion.

tion ponds, trickling filters, final settling tanks, or sand filters, before disposal. The small quantity of liquid (supernatant) from separate sludge digestion tanks is usually returned directly to the plain settling tanks at the inlet.

a. Irrigation. Settled sewage is disposed of by surface or subsurface irrigation (fig 6-5) as follows:

(1) Surface irrigation.

(a) Method. Where soil conditions are suitable and there is no danger of contaminating ground water or surface water supply, settled sewage may be distributed over pervious ground and allowed to evaporate and percolate into the soil.

(b) Recommended uses.

Surface irrigation requires a larger area than other disposal methods. An arid climate with a high rate of evaporation is favorable. It is practicable only where the soil is reasonably pervious. Surface irrigation is recommended especially for use in desert and wasteland areas having sandy loam to gravelly soils, and located far enough from populated areas to prevent any nuisance caused by flies and odors.

(2) Subsurface irrigation.

(a) Method. Subsurface irrigation avoids the odor and fly nuisance caused by surface irrigation, but requires laying an underground tile-pipe distribution system. An arid climate is not necessary, but the soil must be pervious enough for absorption.

(b) Recommended uses.

Disposal of the effluent from a septic tank or leaching cesspool by subsurface irrigation is particularly suited to small installations because it avoids above-ground sewage works and eliminates long pipelines to the disposal area. Such a system is easily enlarged by adding septic tanks or cesspools and extending the tile drains. In loam or sandy soils, a 16-foot-deep, 4-foot-diameter leaching cesspool normally provides sewage disposal for four persons for about 4 years.

(c) Limitations. Some type of primary treatment such as a septic

or settling tank or a leaching cesspool (para 6-8) is required to remove grease and suspended solids. The length of time the system can be used depends on the permeability of the soil and the preliminary removal of grease and solids. In time, the ground and distribution system may become clogged and the area must be abandoned, unless a thorough flushing or cleaning permits further use.

b. Oxidation ponds.

(1) Method. An oxidation pond is a relatively large, shallow, artificial or natural pond into which settled sewage is discharged for purification by sunlight and air. Single ponds or ponds in series may be used (fig 6-6); a series of three or more is recommended. Bacteria feed on the organic compounds in the sewage, the supporting oxygen being absorbed from the air in contact with the surface of the pond. This action converts the sewage into stable compounds free of annoying characteristics. Such ponds may discharge into a natural waterway or may depend entirely on evaporation and percolation for final disposal.

(2) Recommended uses. Oxidation ponds are simple and economical and are recommended for use under the following conditions:

(a) If complete treatment is required.

(b) If suitable location is available $\frac{1}{2}$ to 1 mile from habitations.

(c) If prolonged freezing does not occur.

c. Trickling filters.

(1) Method. A trickling filter (figs 6-3 and 6-4) is a bed of crushed stone, screened gravel, slag, clinker, or similar material which receives settled sewage discharged from fixed spray nozzles or a moving distributor. As the sewage trickles down through the bed, the organic matter is stabilized on the film coating the filter material through the action of bacteria. This film is normally a dark green color on the surface, but it is a gray gelatinous coating below the surface. Brown and black surface films are indicative of poor performance. The effluent passes through

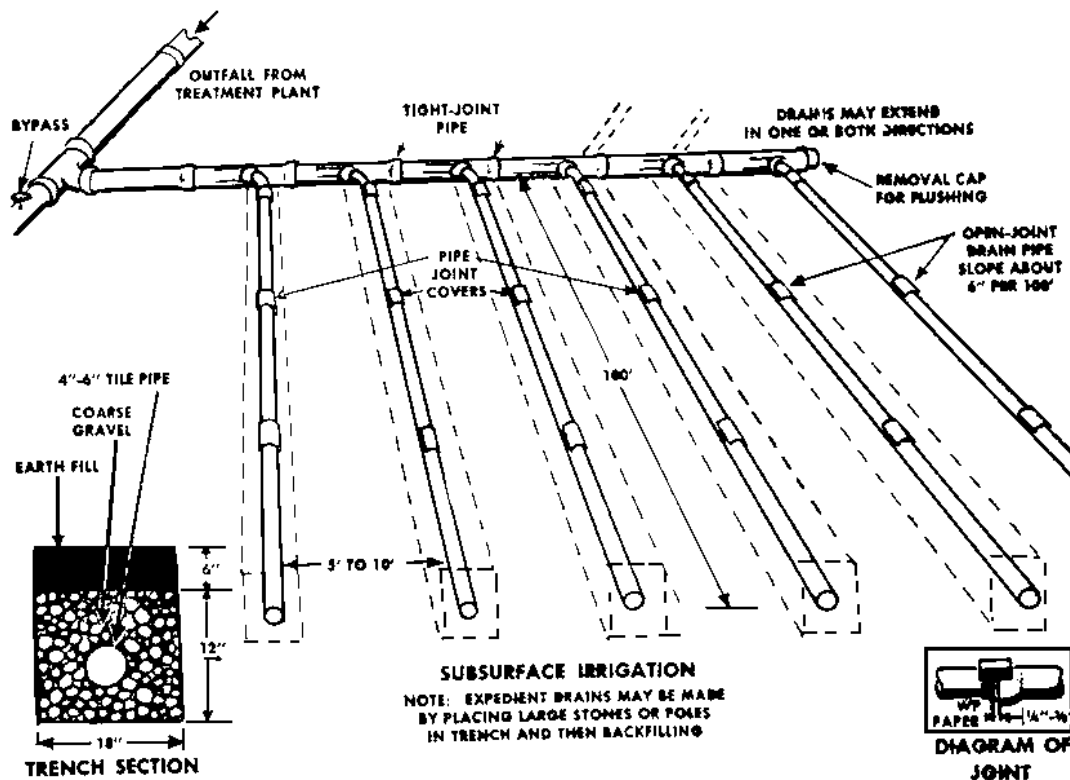
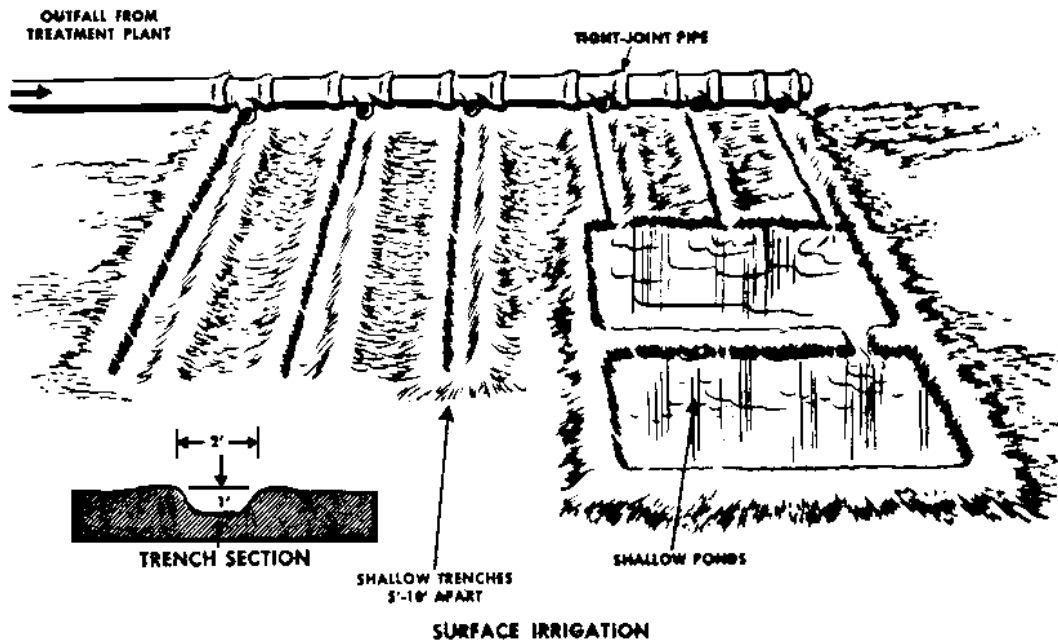


Figure 6-5. Surface and subsurface irrigation.

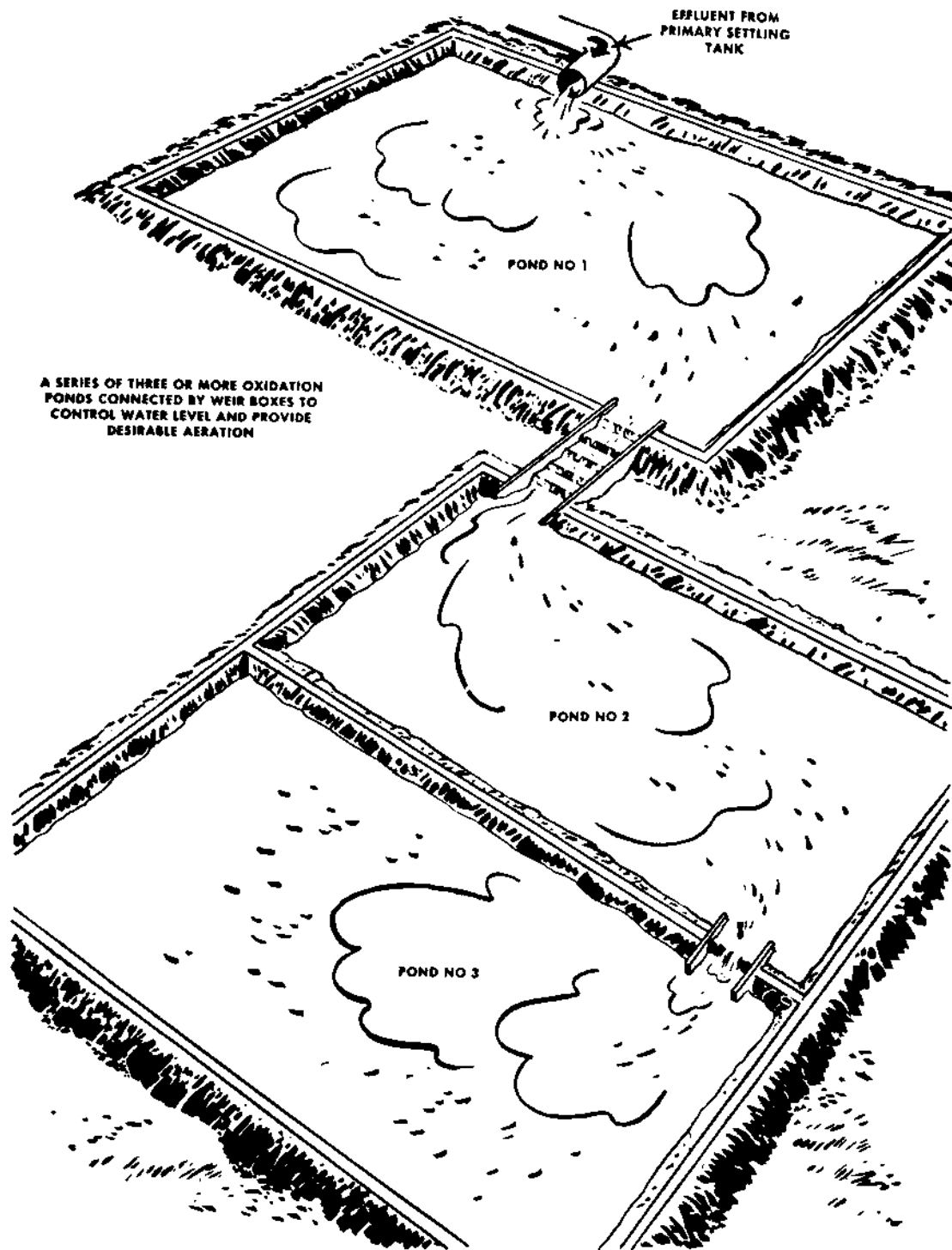


Figure 6-6. Oxidation ponds.

the stone and is collected in a system of underdrains. Periodically some of the slime coating of the stone loosens and is carried off with the filtered effluent. Final settling tanks are omitted in some cases but are desirable to settle out this slime and give a higher degree of purification.

(2) Recommended uses. Trickling filters are recommended for use in theaters of operations when complete treatment is required, provided the following conditions are met:

(a) Required equipment is available or spray nozzles can be obtained or improvised.

(b) Suitable crushed stone, screened gravel, slag, or clinker is readily available.

(c) Simpler treatment methods, such as oxidation ponds, are not practical.

d. Final settling tanks. Final settling tanks are used where the small quantity of slime that accompanies the flow from the trickling filter must be removed. They reduce the velocity of flow to allow settlement of the slime and unsettled solids. These are removed frequently to prevent their becoming septic and are disposed of with the sludge (par 6-6).

e. Sand filters.

(1) Description. A sand filter consists of a bed of uniformly graded .01-.02-inch sand, a pipe or open-trough system for distributing the effluent over the surface to a depth of 1 to 4 inches, and a drainage system for removing the filtered effluent. The sand beds are usually 2 to 4 feet deep, with open-joint-tile or perforated-pipe drains surrounded by graded gravel and spaced at 12-foot centers along the bottom of the bed. As the settled sewage seeps through the sand, most of the fine suspended matter stays on the surface or adheres to the grains near the surface. This matter develops into a gelatinous growth which is necessary for proper treatment because it supports growth of microbic organisms which break down the organic matter. The gelatinous growth occasionally becomes a hard mat and for this reason, the top layer of sand must be scraped off occasionally. The dissolved organic matter in the

liquid is oxidized by the action of air and bacteria in the gelatinous growth on the surface of the bed.

(2) Operation. Sand filters are operated in intermittent dosing, at least 16 hours being needed between dosings to allow the sewage to percolate through the bed and to permit air to fill the voids in the sand. For continued operation, the filter should be divided into 3 or more sections.

(3) Limitations. While a high degree of purification is achieved by sand filters, the high cost and large space requirements limit their use. When such filters are preceded by Imhoff tanks, it is estimated that $\frac{1}{4}$ acre of sand filter bed 3 feet deep is required per 1,000 population; when preceded by septic tanks, about $\frac{1}{3}$ acre per 1,000 population is required.

(4) Recommended use. Sand filters are recommended for use where a high degree of purification is required and where natural sand beds that require only leveling and the installation of drains are already available.

6-8. SEPTIC TANKS AND CESSPOOLS

In a cesspool (fig 6-7), the sewage is allowed to stand, the solids settle to the bottom and are digested, the grease and floating materials rise to the top forming a heavy mat, and the liquids percolate through the side walls into the soil. Excess liquids are sometimes piped to a subsurface irrigation or other system. Solids must be cleaned out periodically by pumping or bailing. A septic tank (fig 6-7) is essentially the same as a cesspool, except that liquid does not percolate through the walls into the earth and constant liquid level is maintained. The sewage enters at one end and the solids settle to the bottom as the sewage slowly flows through the tank. The solids at the bottom form a sludge that digests and is removed from the tank periodically. The liquid is disposed of by dilution or irrigation, or is further treated as described in paragraph 6-5b.

6-9. CHLORINATION

Chlorine can be applied to raw, settled, or treated sewage for disinfection and purification.

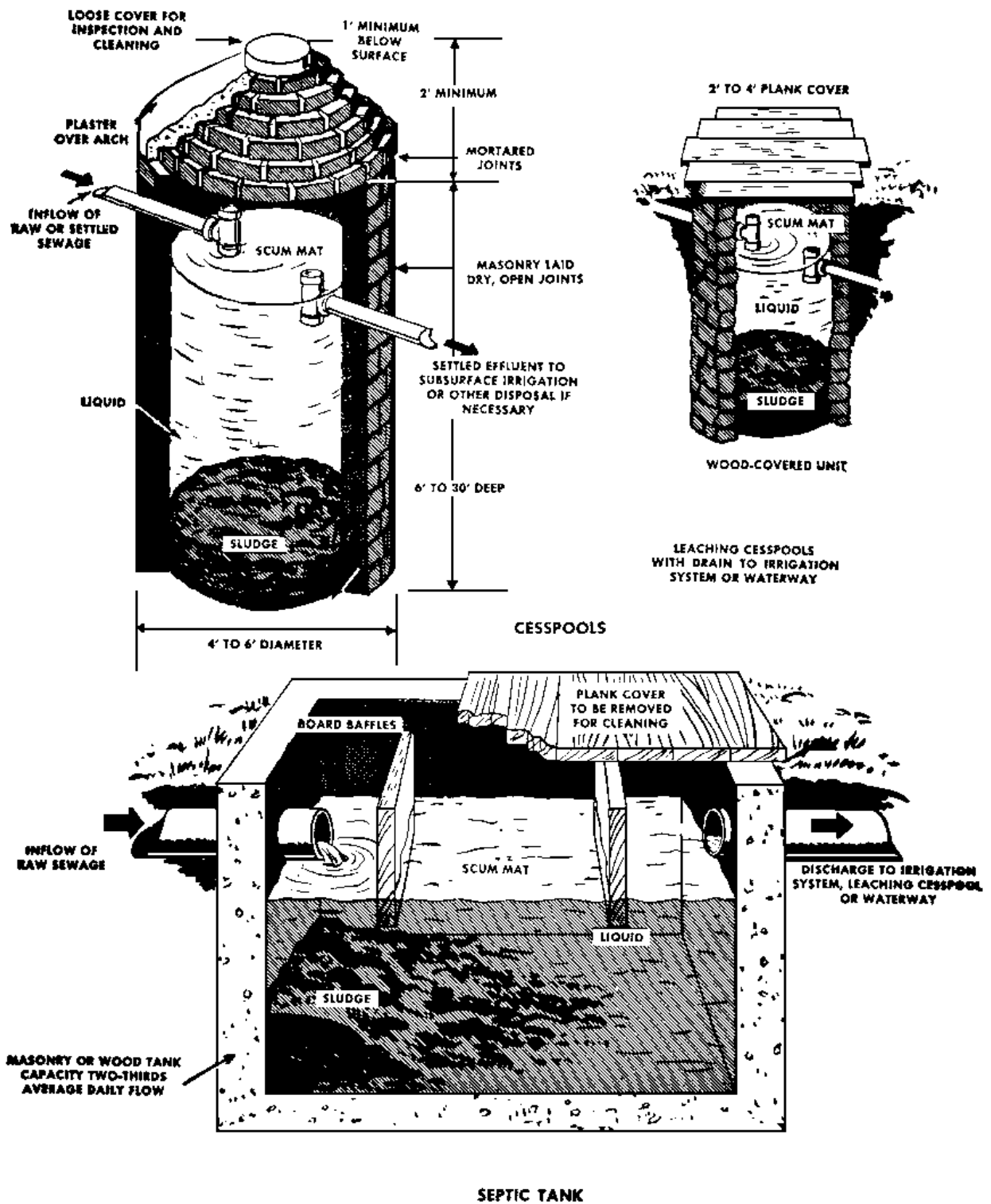


Figure 6-7. Septic tank and cesspool.

tion, to retard BOD, to reduce odors, and to control the breeding of flies. It is often used to disinfect the effluent during periods of reduced flow in streams used for dilution and during periods when a treatment plant must be bypassed for cleaning and repairs. Chlorine also can be used for continuous treatment where dilution is inadequate.

6-10. BASIC PLAN AND DESIGN

a. Basic plan. Before beginning actual construction of a sewerage system, a basic plan is prepared. This plan, which is first drafted in sketch form, shows the layout of the collection, treatment, and disposal facilities. In preparing the plan, the following must be considered:

(1) The oral or written job directive, issued by higher headquarters, specifying that waterborne sewage disposal will be provided. It may furnish additional data on anticipated population and other requirements of the system.

(2) The requirements of the sewage disposal system, determined by the answers to the following questions:

(a) Are all units of the installation to be served by one sewerage system or will two or more systems be required?

(b) Is enough water available for the operation of a waterborne sewage system?

(c) What is the anticipated sewage-contribution population and what is the daily quantity of sewage which must be disposed of (para 6-3)?

(d) Can the sewage be disposed of by dilution only or will treatment be required (para 6-4)?

(e) Is there an existing civilian system which can be rehabilitated and used in connection with the proposed military system?

b. Elements of the basic plan. The basic plan must include the following information:

(1) Location of all buildings which are to be connected to the sewage system.

(2) Location, grade, and required capacity of all lateral, branch, trunk, and outfall sewers.

(3) If treatment is required, decision as to treatment method to be used and location of treatment plant (para 6-5).

(4) Method and point of final disposal.

c. Preliminary investigations.

Preliminary investigations are carried on while the basic plan is being formulated and must be completed before final designs can be prepared. These investigations include:

(1) A study of existing civilian or military maps and aerial photographs with respect to natural and artificial terrain features affecting layout and planning of the system.

(2) A site reconnaissance to check the results of the map study and to provide additional design data.

(3) Soil borings, if necessary, to locate the water table and rock or underground structures which would affect the excavation of trenches and the elevation of the sewer.

(4) Topographic surveys as required for the location and design of sewers, treatment plants, and disposal systems.

(5) Profiles along all proposed sewer lines with elevations of critical house inlets.

d. Design of component units. The final design of units of the sewerage system, such as sewer lines and treatment plant, is completed after the basic plan is formulated and the preliminary investigations are made. Military sewerage systems are designed for the most simple construction and operation. Only prefabricated equipment that is known to be available is considered. The elaborate processes common in civilian treatment plants are not used in temporary military installations.

6-11. SEWERS

a. Capacity.

(1) Sewer capacity is determined by the number of people the system serves, based on flow per capita per day (para 6-3). An allowance of three times the average flow

is made in the design of all sewers and channels within the treatment plant for peak flows in the morning and late afternoon. Thus, if an average flow of 25 gpd is used in the design of the sewers, the peak flow is computed on a 75-gpd basis. Average flow is used in the design of plant units, including settling tanks and filters.

(2) In choosing pipe sizes, the time interval between peak flows and the rather large reservoir capacity of the sewers should be carefully considered. The time interval between peak flows is frequently long enough for one peak flow to pass from a lateral into an interceptor before the next peak flow begins. The capacity of the lines to hold part of the load as the flow increases also reduces the peak loads on the interceptors and outfall. Careful study of these factors may reveal that considerable economy in the selection of pipe sizes is possible.

(3) Ground water seeping into sewers increases the required capacity. The amount of ground water that finds its way, into the sewer depends on the tightness of sewer joints and manhole construction the height of the ground-water table, and the permeability of the soil. Where the sewer is below the water table, the infiltration may reach 10,000 gpd per mile of pipe.

b. Size. The size of sewer required to carry a given capacity depends on the slope of the sewer and the resistance to flow caused by the interior surface of the pipe. The sewer should flow full at design capacity. Pipes less than 4 inches in diameter are not used because they clog and require frequent cleaning. Four-inch pipe may be used on house connections; however, six-inch pipe should be used if available. Lateral sewers must not be less than 6 inches in diameter and should be 8 inches or more.

(1) **Velocity.** The flow, in a sewer must be rapid enough to prevent suspended solids from settling on the bottom. Velocity in a sewer depends on its size, depth of liquid, slope, and coefficient of roughness of the pipe.

(a) **Slope.** A sewer having a slope steep enough to produce a minimum

flow of 2 fps when flowing full is generally desirable, although sewers may be designed for a minimum 1.5-fps velocity when such design eliminates pumping or excessive excavation. However, higher velocities are more efficient, less liable to stoppage, and permit the use of smaller pipes. Table 6-2 gives required pipe sizes and slopes for various quantities of sewage at the minimum velocities of 1.5 and 2 fps.

(b) **Pumping.** Pumping is necessary if the slope does not produce required velocity or where sewage must be lifted to a higher elevation. Sewage can be pumped through pressure lines (force mains) regardless of their slope, or it can be raised high enough at pumping stations so gravity provides the required velocity. The hydraulic principles in lesson 4 are used to determine the size of the pipe, the velocity of flow, and the horsepower requirements of pumps. Non-clogging centrifugal sewage pumps are most satisfactory for pumping sewage or, if the quantity is small, pneumatic ejectors can be used. In emergencies, open impeller type centrifugal water pumps can be used for pumping well-screened sewage. Pumps are usually set in pairs to give 100-percent standby service during maximum flow. When the sewage in a sump reaches a predetermined depth, a float switch starts a pump. When the sump is almost empty an automatic switch stops the pump. The starting-switch control of the standby pump is set to start at a slightly higher water level than the first pump and to stop at the same low-water level. Starting switches are set so pumps operate alternately, or the switch mechanism is changed at frequent intervals so each pump operates about the same length of time. Pump motors are located so they do not become flooded if they fail to function, or a shutoff valve is provided to stop the flow when the water level endangers the drive unit. Pump stations may be entirely manually controlled.

(2) **Resistance.** Resistance to flow offered by the interior surface of the sewer depends on the pipe material. Average resistance values have been determined for various materials and are allowed for in pipe-flow charts and tables (table 6-2 and fig 6-8).

Figure 6-2. Required Sizes of Sewers. Flow based on Kutter's Formula, $n = 0.013$

Pipe diameter (inches)	2-fps velocity			1.5-fps velocity		
	Slope (ft. per hundred ft.)	Discharge (gpm)	Population capacity*	Slope (ft. per hundred ft.)	Discharge (gpm)	Population capacity*
6	0.63	178	3,300	0.36	132	2,500
8	0.40	314	6,000	0.23	235	4,500
10	0.28	490	9,000	0.16	368	7,000
12	0.21	707	13,000	0.12	530	10,000
14	0.17	960	18,000	0.095	721	13,000
15	0.15	1,104	21,000	0.086	828	15,000
16	0.14	1,260	24,000	0.078	942	18,000
18	0.12	1,500	30,000	0.067	1,192	22,000
20	0.10	1,970	37,000	0.056	1,472	28,000
21	0.09	2,160	41,000	0.053	1,623	31,000
24	0.076	2,825	54,000	0.044	2,120	40,000

* Population capacity is based on a peak flow rate of 75 gpd.

c. Type. Sewers may be built in many shapes and of many materials. Vitrified-clay, asbestos-cement, and concrete pipe are most common for military work, although cast-iron, wood, steel, and bituminized-fiber pipe also may be used. Cast-iron pipe may be used for shallow sewers placed under roadways, since there is a danger of crushing other type of pipe. When pumping is necessary, the force main should be cast-iron, steel, wood-stave, or asbestos cement pipe. Sewers can be improvised from local materials such as stone, brick, timber, or concrete laid in trenches. They should be covered and made watertight to prevent infiltration of ground and surface water and to avoid unpleasant odors.

d. Layout. To avoid deep excavations, sewers are located along natural drainage lines. If possible, they are not laid longitudinally under roadways. Road crossings are kept to a minimum. Where necessary, road crossings are reinforced by placing a low-grade concrete in the trench to a level of 4 inches above the top of the pipe. In traffic areas, sewers should be covered with at least 2 feet of well-compacted earth. Connections adjoining buildings may need only 1 foot of cover. Manholes (fig 6-9) are located at each change of direction or slope, also located at every change in pipe size; and generally are placed at the end of each lateral. On straight sections of sewers, the maximum distance between manholes is 400 feet if the sewer is less than 18 inches and 600 feet if greater than 18 inches.

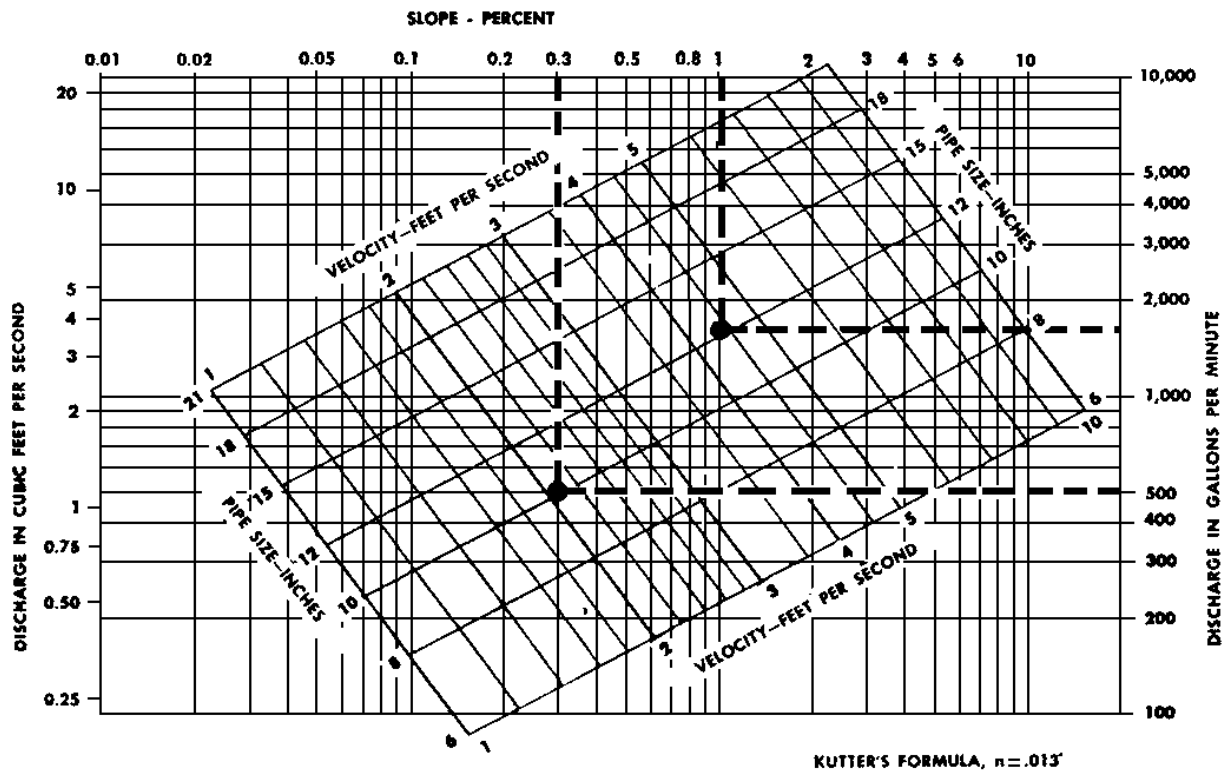
Where sewers connect, a Y-channel is formed in the base of the manhole. If the flow is at least 3 fps, lampholes (fig 6-9) are sometimes used instead of manholes at the ends of laterals and at alternated manhole locations where no junctions are made with incoming lines.

6-12. TREATMENT PLANTS

a. Site. The main consideration in selecting the treatment-plant site is the location of the final receiving ground of diluting water. The treatment plant should be down-wind of populated areas and far enough away to avoid odor nuisance. Other factors influencing site selection are elevation above floodwater level and ground slope for gravity operation. Unless there is a 10- to 15-foot drop through complete treatment plants to provide gravity flow, sewage must be pumped.

b. Layout. Figure 6-2 shows the layout of a standard type treatment plant. All treatment plants should have a bypass for use during repair and maintenance. Plants serving more than 10,000 persons generally are built with multiple tanks, filters, and other facilities; and piping is arranged so parts of the plant can be bypassed for cleaning and repair without putting the entire installation out of operation.

c. Capacity. Designs of tanks, basins, and other units within a treatment plant are based on the average anticipated flow for the required retention period. All pipes and channels within the plant are designed to



EXAMPLES FOR USE OF DIAGRAM.

(1) ASSUME A REQUIRED DISCHARGE OF 500 GPM, AVAILABLE GROUND SLOPE OF 0.3%, AND A MINIMUM ALLOWABLE VELOCITY OF 2 FPS.

ENTER DIAGRAM FROM 500 GPM AT RIGHT ALONG DOTTED LINE TO INTERSECTION WITH A VERTICAL LINE FROM 0.3% SLOPE AT TOP. THIS INTERSECTION SHOWS THAT A 10-INCH PIPE IS REQUIRED AND WILL GIVE A 2.1-FPS VELOCITY.

(2) REQUIRED: THE VELOCITY AND DISCHARGE OF AN EXISTING 12-INCH SEWER ON A 1.0% SLOPE.

ENTER AT THE TOP, FOLLOWING DOWNWARDS ALONG THE DOT-AND-DASH LINE FROM 1% SLOPE TO AN INTERSECTION WITH LINE 12-12 SHOWING PIPE SIZE. THE DIAGONAL FROM THIS POINT TO THE LOWER RIGHT INDICATES A VELOCITY OF ABOUT 4.4 FPS; THE HORIZONTAL DOT AND DASH LINE TO THE RIGHT INDICATE A DISCHARGE OF APPROXIMATELY 1,600 GPM.

Figure 6-8. Pipe-flow for sewers and drains.

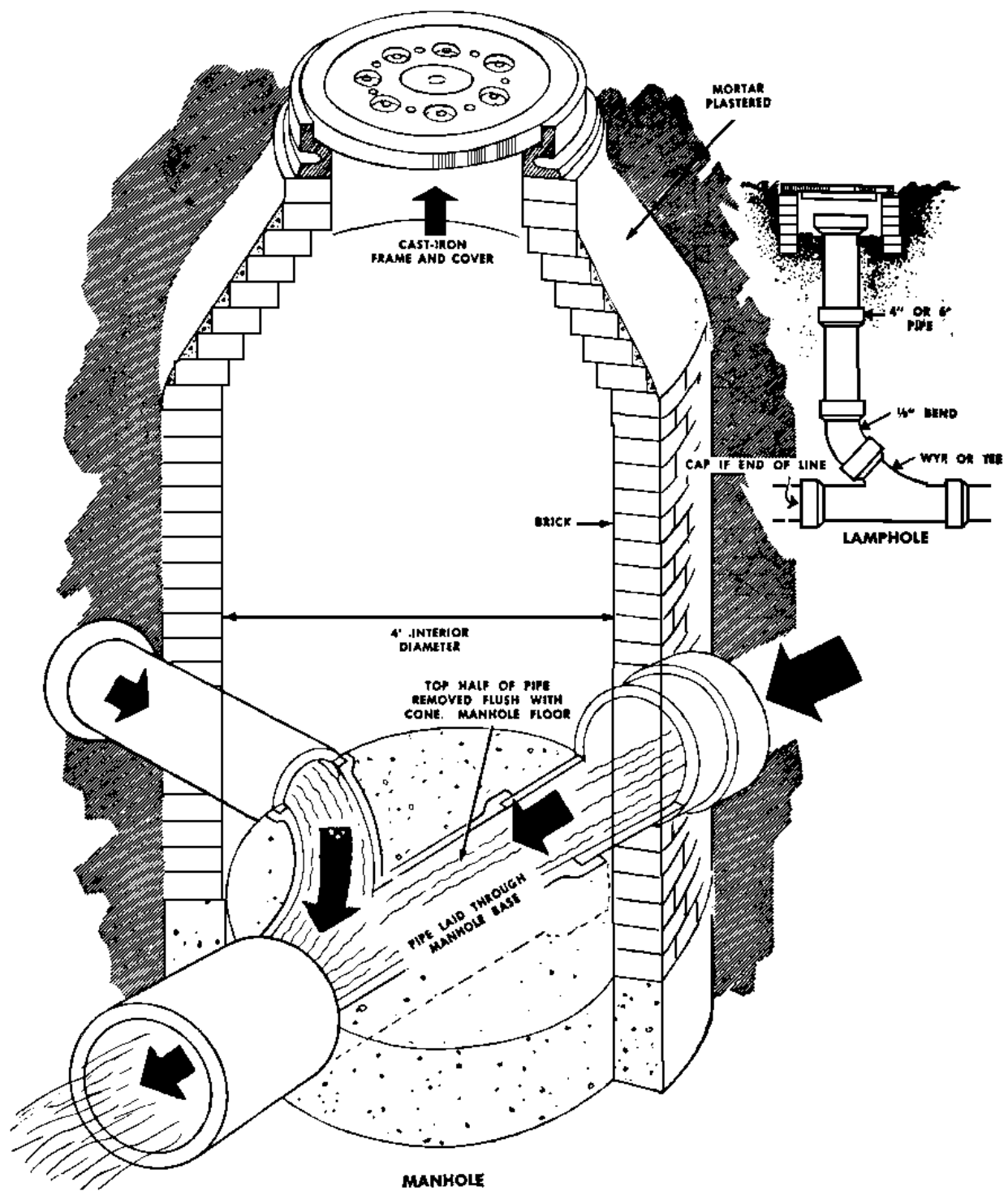


Figure 6-9. Manhole and lamphole.

carry the peak flow at velocities not less than 2 fps.

d. Materials. Concrete, brick or masonry are the best materials for treatment-plant construction. Local stone and similar building materials should be used where economical. Light steel tanks are suitable where anticipated period of use is short. It is recommended that wood be considered in planning temporary installations because of the saving in cost and labor. However, wood construction requires more maintenance than masonry or concrete.

6-13. SURFACE IRRIGATION

a. Rate of application. Disposal rates of sewage by surface irrigation vary with the permeability of the soil, ranging as high as 60,000 gallons per acre per day. To estimate the rate of application, dig a hole 1 foot square and 1 foot deep and fill it with water. When the water has seeped away, but the bottom of the hole is still wet, pour 6 inches of water in the hole and note time required for water level to drop 1 inch. Use table 6-3 to determine rate of sewage application. Surface irrigation areas are operated on the principle of intermittent dosing.

b. Ground recovery. Ground used for surface irrigation must be rested. With use, the surface will clog and must be scraped off. Allowance for resting, recovery, and rainfall is included in table 6-3.

TABLE 6-3. Application Rates of Sewage by Surface Irrigation

Time for water to fall 1 inch in test hole ¹ (minutes)	Average rate of application (gallons per acre per day)
1	57,700
2	46,800
5	34,800
10	25,000
30	12,000
60	8,700

¹Figures are approximate and are suggested for use as a guide only.

²Test: Fill 1 foot square hole to a depth of 1 foot with water and allow to seep away. While bottom of hole is still wet, fill again to depth of 6 inches and observe time in minutes for water to fall 1 inch in test hole. This time in minutes corresponds to permissible rates of application in table.

6-14. SUBSURFACE IRRIGATION

Settled sewage can be disposed of by subsurface irrigation, a method commonly used in conjunction with cesspools or

septic tanks at small installations. A typical layout for subsurface irrigation is shown in figure 6-5. The main distributors are laid with tight, but not necessarily waterproof, joints. The tile pipe of the laterals, usually 4 to 6 inches in diameter, is laid with a ¼- to 3/8-inch gap between sections, the top two-thirds of the joint being covered with roofing paper. If perforated bituminized fiber pipe is available, it is laid with split collar joints and perforations downward. Laterals are laid in a gravel filled trench with about a 6-inch fall per 100 feet for unregulated flow and about a 4-inch fall per 100 feet where a dosing system is used. Laterals are spaced 5 to 100 feet long. The length of tile drain system is computed using a test hole dug to the depth of the proposed tile drains (para 6-13 and table 6-4).

TABLE 6-4. Application Rates of Sewage by Sub-surface Irrigation

Time for water to fall 1 inch in test hole ¹ (minutes)	Average rate of application (gpd per 100 feet of trench 18 inches wide)
1	800
2	480
5	360
10	255
30	120
60	90

¹Figures are approximate and are suggested for use as a guide only.

²Test: Fill 1 foot square hole to a depth of 1 foot with water and allow to seep away. While bottom of hole is still wet, fill again to depth of 6 inches and observe time in minutes for water to fall 1 inch in test hole. This time in minutes corresponds to permissible rates of application in table.

6-15. SCREENS

Screens (fig 6-10) can be used for removing large solids from sewage before it enters pumps or treatment plants. For rough screening, bars are installed longitudinally in a channel, 1 to 1½ inches apart, clear measurement. The bars should have a slope of approximately 1 vertical to 2 horizontal. Screens with 1-inch openings collect 1 to 3 cubic feet of screenings per million gallons of sewage. Screens are usually built with an overflow bypass so a clogged screen does not cause a stoppage. Screens are cleaned by hand.

6-16. PLAIN SETTLING TANKS

Plain settling tanks (fig 6-11) permit settling of the suspended solids in sewage, a

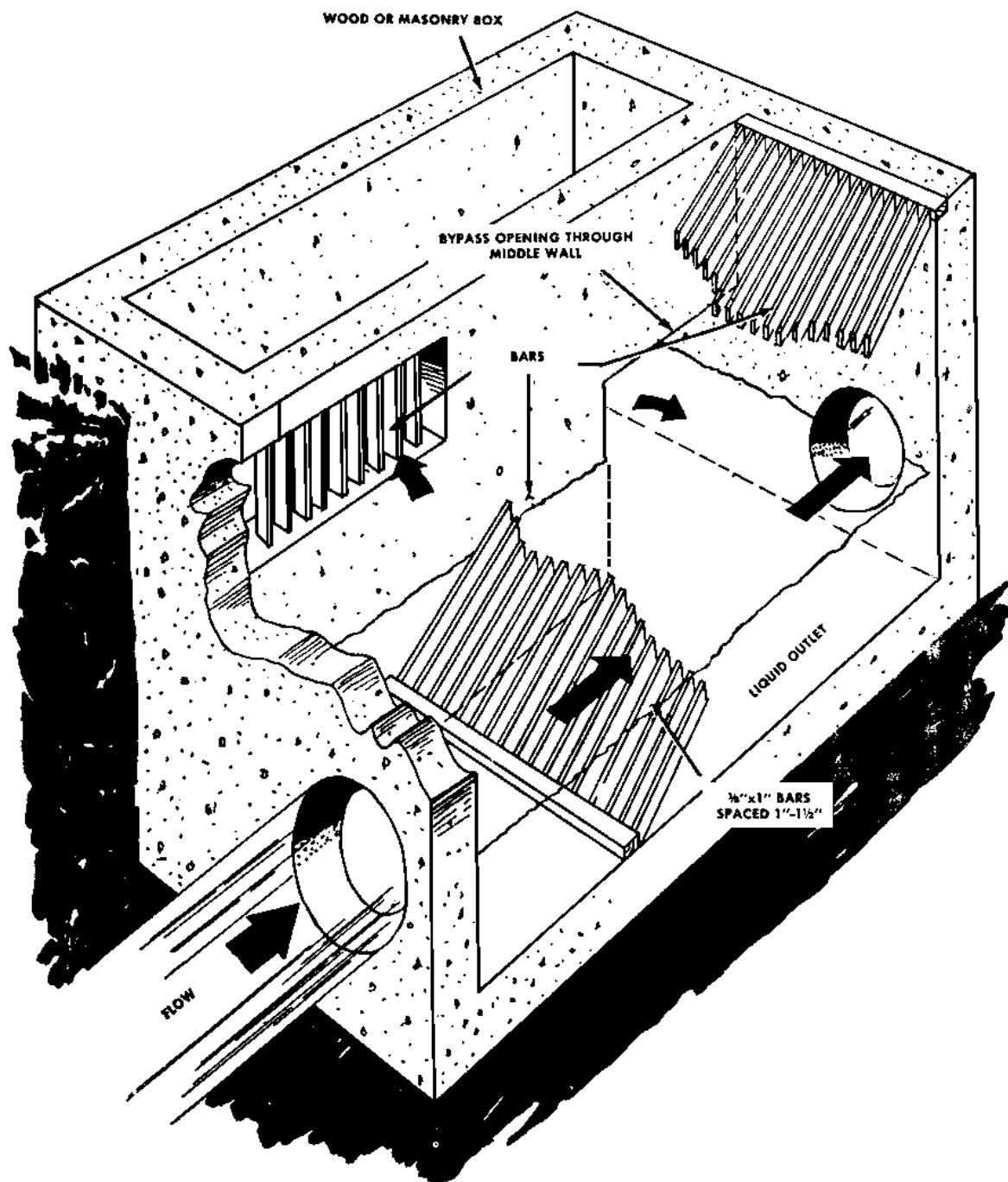


Figure 6-10. Bar screen with bypass.

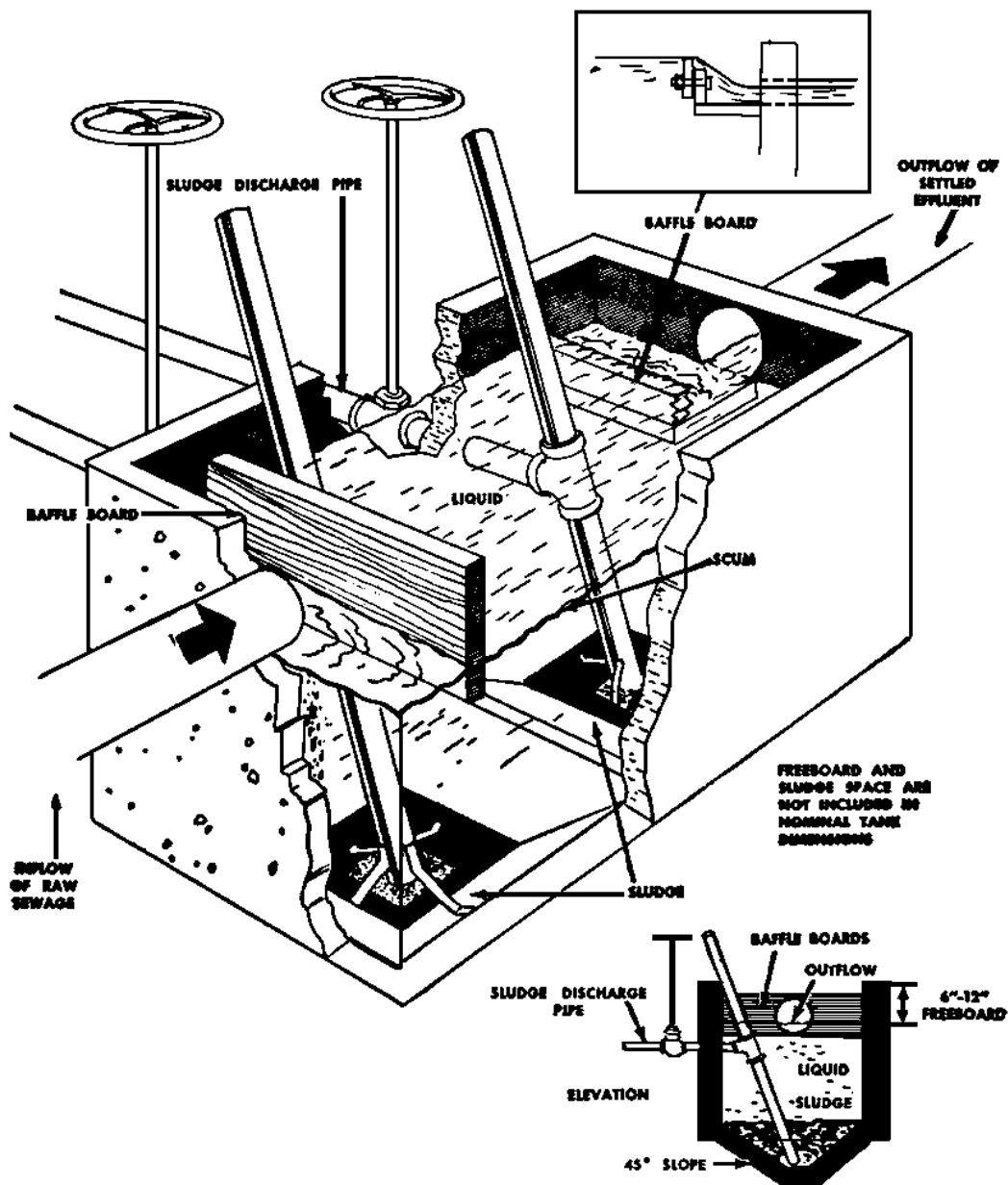


Figure 6-11. Plain settling tank with hopper bottom.

process called plan sedimentation. Sewage is detained in the tank long enough and at velocity low enough so suspended matter settles out. However, if retention period is too long, the settled solids will decompose. Sludge from these tanks goes to separate sludge digestion tanks, while the effluent is usually further treated in trickling filters, sand filters; or oxidation ponds.

a. Design factors. Factors considered in designing settling tanks are the quantity of sewage to be handled, velocity of flow, length of detention period, the dimensions required, method of sludge removal, and available materials.

(1) Velocity of flow. The average velocity through the settling tank should not exceed 1.25 feet per minute at the peak rate of flow and preferably should be less.

(2) Detention period. Detention period within the tank varies from 2 to 3 hours for average flow, 2 or 2½ hours being recommended.

(3) Dimensions.

(a) Typical tank dimensions, exclusive of sludge space and freeboard, based on 2½-hour detention and 7-foot depth, are--

10 by 25 ft for 5,000 population
12½ by 40 ft for 10,000 population
20 by 50 ft for 20,000 population

(b) Tank depths vary from 5 to 10 feet, 7 feet being average.

(c) Inlets and outlets must be large enough to carry peak flows. Baffles should be used at inlets so flow is distributed throughout the tank and weirs at outlets so effluent is drawn from the surface for the full width of the tank. The outlet flow is regulated by an adjustable weir.

(4) Sludge removal. Some tanks have hopper bottoms (fig 6-11) facilitating sludge removal by the water pressure of the sewage in the tank. Sludge must be removed daily.

(5) Materials. Brick or stone masonry, gunite, sheet metal, or wood may be used to construct settling tanks. In firm ground such as clay, an unlined pit may be feasible. Sludge

and liquid are removed from such pits by gravity flow if possible, otherwise by pumping.

b. Design procedure.

(1) Tank dimensions are determined by the following calculations:

(a) Detention period in hours times gpd times contributing population divided by 180 equals cubic feet of tank capacity required.

(b) The required tank capacity in cubic feet divided by the depth, which should not exceed 10 feet, gives the surface area.

(c) In rectangular tanks the ratio of length to width should not exceed 5 to 1 and is preferably about 3 to 1.

(2) Additional allowances are necessary in the design of a tank to provide free-board and allow space for the sludge. Slopes of the sludge hopper should be at least 1½ vertical to 1 horizontal.

6-17. SEPARATE SLUDGE DIGESTION TANKS

Raw sludge from settling tanks may be discharged into sludge digestion tanks for septic decomposition. The solids, when first deposited in the tank, form a thin low-density sludge. As decomposition progresses, digested material settles to the bottom. As the depth of sludge increases, the solids in the bottom compact. Thus the sludge in the tank varies greatly in fluidity from top to bottom. The rate at which digestion and the resulting change in fluidity take place depends on temperature and alkalinity, which should not fall below a pH value of 6.8. In temperate climates where the average temperature is about 60°F, sludge tanks should provide storage for 2 months. This period of digestion produces a well-digested, inoffensive sludge that dries rapidly.

a. Design factors. Separate sludge digestion tanks should provide 3 cubic feet per capita in plants using partial treatment only, and 4.5 cubic feet per capita in plants that return the sludge from final settling tanks to the plain settling tank or directly to the sludge digestion tank. The design basis allows a reasonably deep stratum of clarified

supernatant which is withdrawn from the digester. In tropical climates or in installations having sludge-heating facilities, tank capacity may be reduced to two-thirds of the above volumes. Sludge tanks are preferably 15 to 25 feet deep, but practical construction may limit the depth to 10 or 15 feet.

b. Types of tanks. The simplest type of digestion tank is an uncovered earth basin which receives the settled sludge from the settling tank by gravity flow. Digested sludge is drawn off at the bottom, which should be cone or hopper shaped to facilitate the outflow of sludge. Concrete-lined tanks are preferred, although brick or some masonry, gunite, sheet-metal, or wood tanks may be used. In firm ground such as clay, an unlined pit from which the sludge and liquid are removed by pumping may be feasible. The scum and hard mat that forms on the surface should be broken up and forced down into the sludge.

6-18. COMBINATION SETTLING AND DIGESTION TANKS

a. Leaching cesspools. Leaching cesspools (figs 6-7 and 6-12) are closed or covered pits, usually with masonry walls without mortar and an unlined bottom through which liquids percolate into the surrounding soil. Solids settle to the bottom of the pit where they are digested. Occasionally, it may be necessary to pump or bail the pit out with a bucket. Size can be determined by the test described in paragraph 6-13 and table 6-5 although this test is strictly applicable for settled sewage only. Leaching cesspools range from 4 to 6 feet in diameter and from 6 to 20 feet deep. Masonry-lined walls are laid dry with open joints to the high-water line. If more than one cesspool is required, they are connected in series and are located at least 20 feet apart.

b. Septic tanks. Septic tanks (fig 6-13) are normally not used when population exceeds 500. They are generally watertight and discharge their effluent into subsurface irrigation systems, oxidation ponds, leaching cesspools, or directly into a waterway.

Solids settle to the bottom of the tank where they are digested.

Table 6-5. Capacity of Leaching Cesspools

Time for water to fall 1 inch in test hole ¹ (minutes)	Required surface area of bottom and side walls in contact with sewage (sq. ft. per 100 gal. per day)
1	19
2	23
5	31
10	44
30	91
60	111

¹ Figures are approximate and are suggested for use as a guide only.

² Test: Fill 1 foot square hole to a depth of 1 foot with water and allow to seep away. While bottom of hole is still wet, fill again to depth of 6 inches and observe time in minutes for water to fall 1 inch in test hole. This time in minutes corresponds to permissible rates of application in table.

(1) Dimensions. Tank capacity should be about two-thirds of an average day's flow which will give a nominal 16-hour retention. Tanks holding less than 500 gallons are not practicable. Septic tanks are usually rectangular in shape, the length being two to three times the width; depths vary from 4 to 12 feet. 7.48 gallons equal 1 cubic foot.

(2) Baffles. Baffles are placed near the inlet and outlet to diffuse the flow and to prevent scum from passing out with the liquid effluent.

(3) Sludge removal. Large tanks are designed with a sloped or hopper-shaped bottom which aids in the concentration of the solids in the removal of the sludge. The sludge is removed periodically through gravity drain lines or by pumping.

(4) Dosing.

(a) A dosing chamber with an automatic siphon is desirable in large tanks when the effluent is disposed of by subsurface irrigation. The capacity of the dosing tank is usually about 80 percent of the volume of the tile drain system it serves. A dosing chamber has two purposes: it permits discharging the effluent at intervals, thus allowing time for one dose to enter the soil and for air to fill the pores before another dose is received; and it distributes effluent uniformly over the entire area.

(b) The action of the dosing siphon is as follows: As liquid rises in the dosing chamber, air trapped in the dome covering the outlet siphon is compressed and forced downward through the longer leg. Further

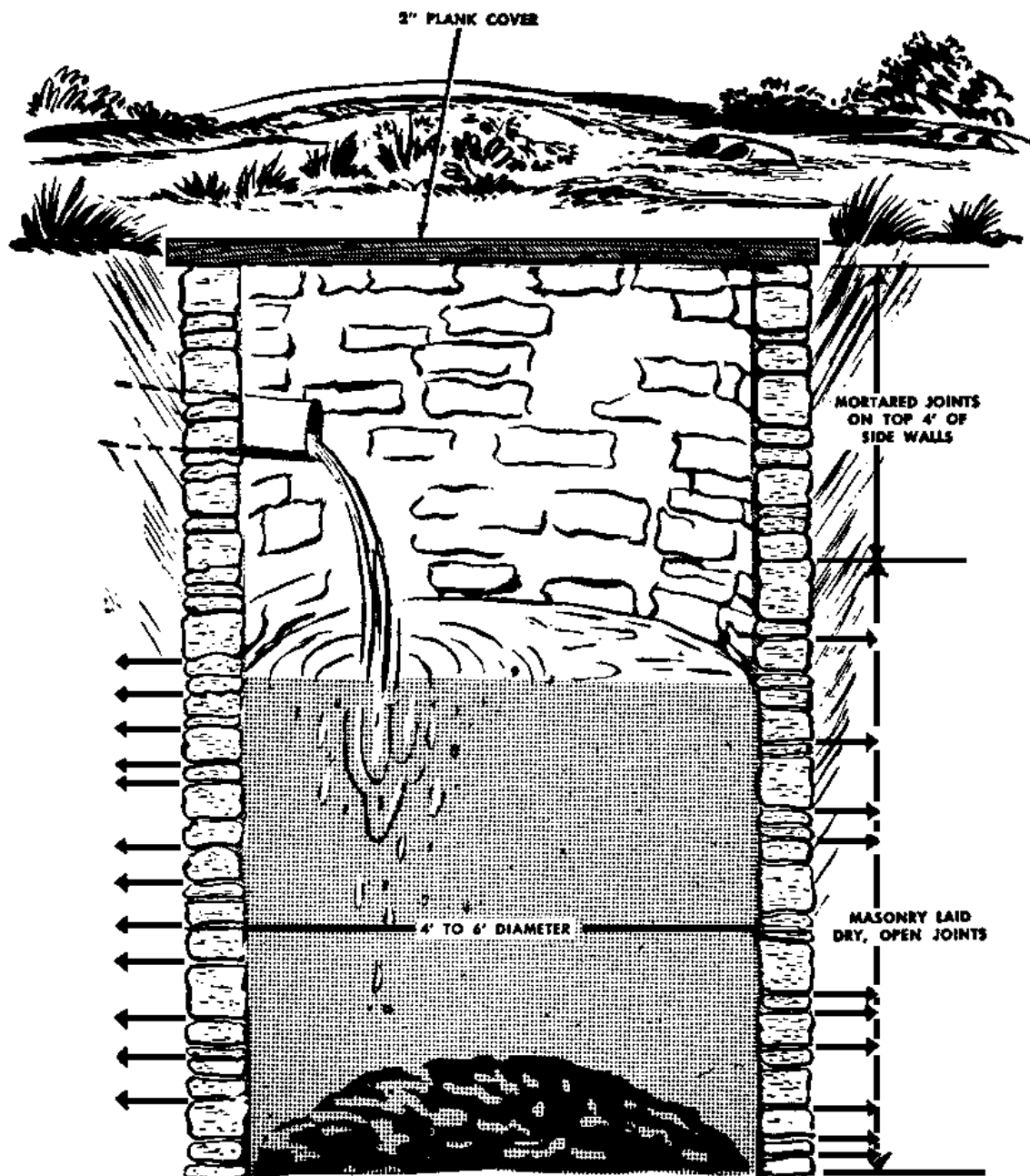


Figure 6-12. Leaching cesspool with wood cover.

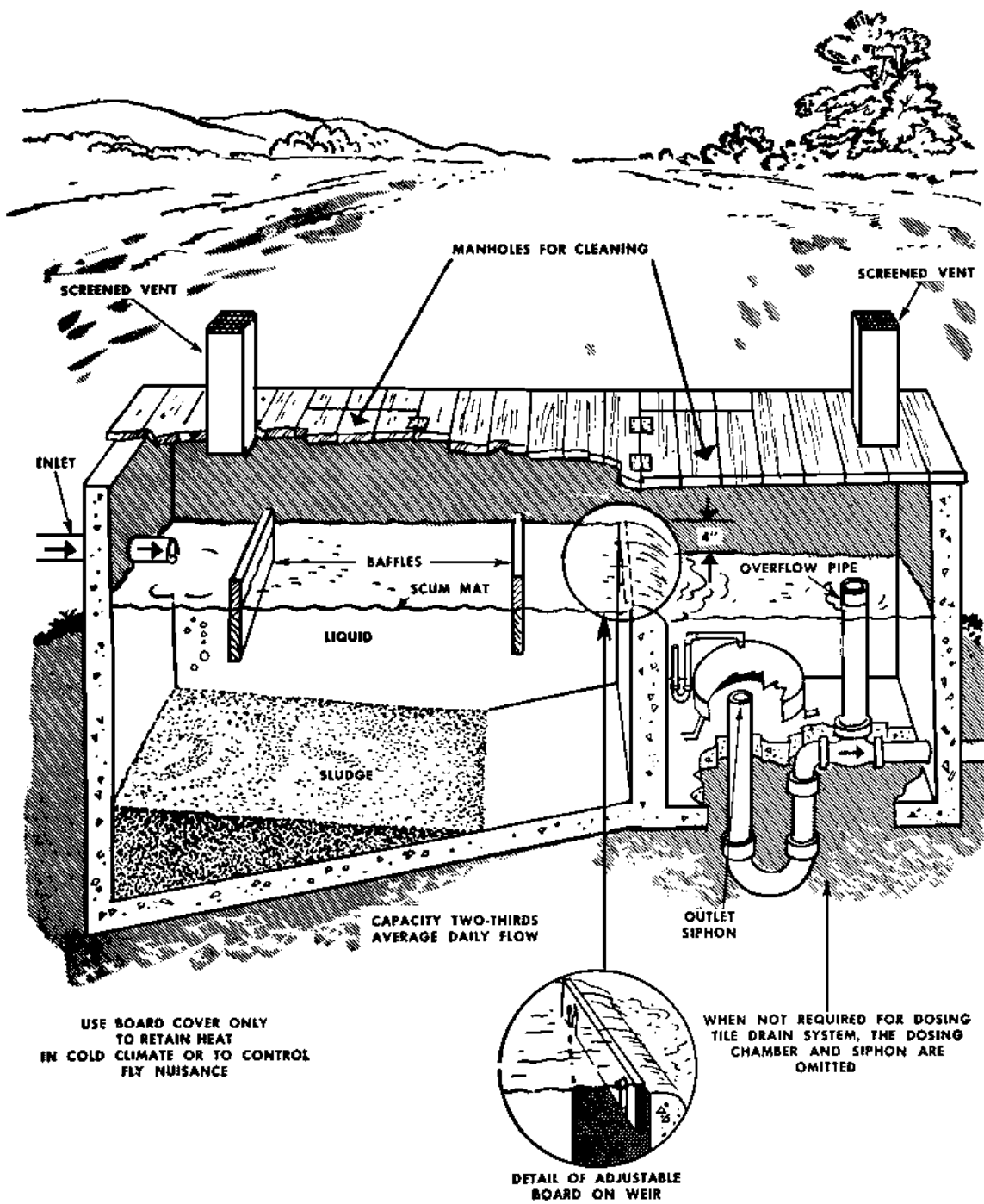


Figure 6-13. Septic tank with dosing chamber.

rise in liquid level forces the air around the bend, allowing it to escape through the shorter leg. Water rushing into the dome to replace this air starts siphon operation, which continues until liquid level drops below bottom rim of dome, breaking the siphon action and stopping the flow. Adjustment in flushing head is made by changing the length of the nipple on the air vent pipe.

c. Imhoff tanks (figs 6-14, 6-15).

(1) An Imhoff tank consists of an upper compartment for settling out solids from the slowly flowing sewage and a lower compartment for digesting the sludge. The upper compartment forms a channel with an approximately 8-inch slot in the bottom. Sides of the slot have a 1 horizontal to 1½ vertical slope and are overlapped to prevent gases formed by digesting sludge from escaping into the upper or "flowing-through" compartment. With an average flow, solids settle in the upper compartment in 2 to 2½ hours, pass downward through the slot, and settle to the bottom of the lower compartment where they are digested. Accumulated solids are removed periodically through a sludge drawoff pipe having its inlet about 1 foot above the tank bottom.

(2) Design of the upper of "flowing-through" compartment is based on the retention period. The lower or digestion compartment is designed to hold 3 cubic feet per capita below a plane 18 inches beneath the bottom of the slot. If sludge from secondary settling is returned to this compartment for digestion, the capacity of the compartment must be increased to 4½ cubic feet per capita.

6-19. SLUDGE DRYING BEDS

a. Lagoons. Sludge from Imhoff and digestion tanks can be disposed of in lagoons or can be dried on natural or artificial beds. Sludge lagoons should be about 6 feet deep and large enough to provide a 6-month storage capacity, about 4 cubic feet per capita. The sludge is removed from the lagoons by hand or by mechanical loading equipment and buried. Sludge pipes should have at least a 3-percent slope plus a

static head of 4 to 6 feet. In open channels, a 1:40 slope is adequate.

b. Drying beds without drains.

Natural sludge drying beds without underdrains are constructed by building earth dikes. They should provide 3 to 4½ square feet of surface per capita, depending on climate and permeability of the soil. Liquid sludge from the digestion tank is applied about 12 inches deep. When dried, it contains about 65 percent moisture and forms a cake about 4 inches thick. This cake is removed with a fork or shovel.

c. Drying beds with drains.

(1) Underdrain sludge drying beds (fig 6-16) consist of a surface layer of sand 6 to 12 inches thick, a 6- to 12-inch layer of gravel below the sand, and underdrains below the gravel layer. The underdrains should be 4- to 6-inch open-joint or perforated pipe spaced 10 to 20 feet apart and should be laid in a V-shaped trench and surrounded with coarse gravel. The required area of a sludge bed is 1 to 1½ square feet per capita; the maximum length is about 100 feet. The bed is subdivided into sections by wood or masonry curbs spaced midway between the drain pipes.

(2) Characteristics and handling of sludge are the same as for natural beds. Drying requires 2 to 4 weeks, depending on humidity and rain-fall. Sand removed with the sludge must be replaced when the thickness of the sand layer is reduced to 4 inches.

6-20. TRICKLING FILTERS

A trickling filter (fig 6-17) is a bed of stone constructed with underdrains and equipped with sprinklers or a distributor to spread settled sewage evenly over the surface. The size of the filter bed is determined on the basis of about 0.35 cubic yard of stone per capita. Desirable hydraulic head between the lowest liquid level in the dosing chamber and the center of the rotary distributor arm is 10 to 12 inches. If sprinkler nozzles are used, head should be sufficient to discharge the maximum flow at the low-water level in the dosing tank. This usually requires a 6- to

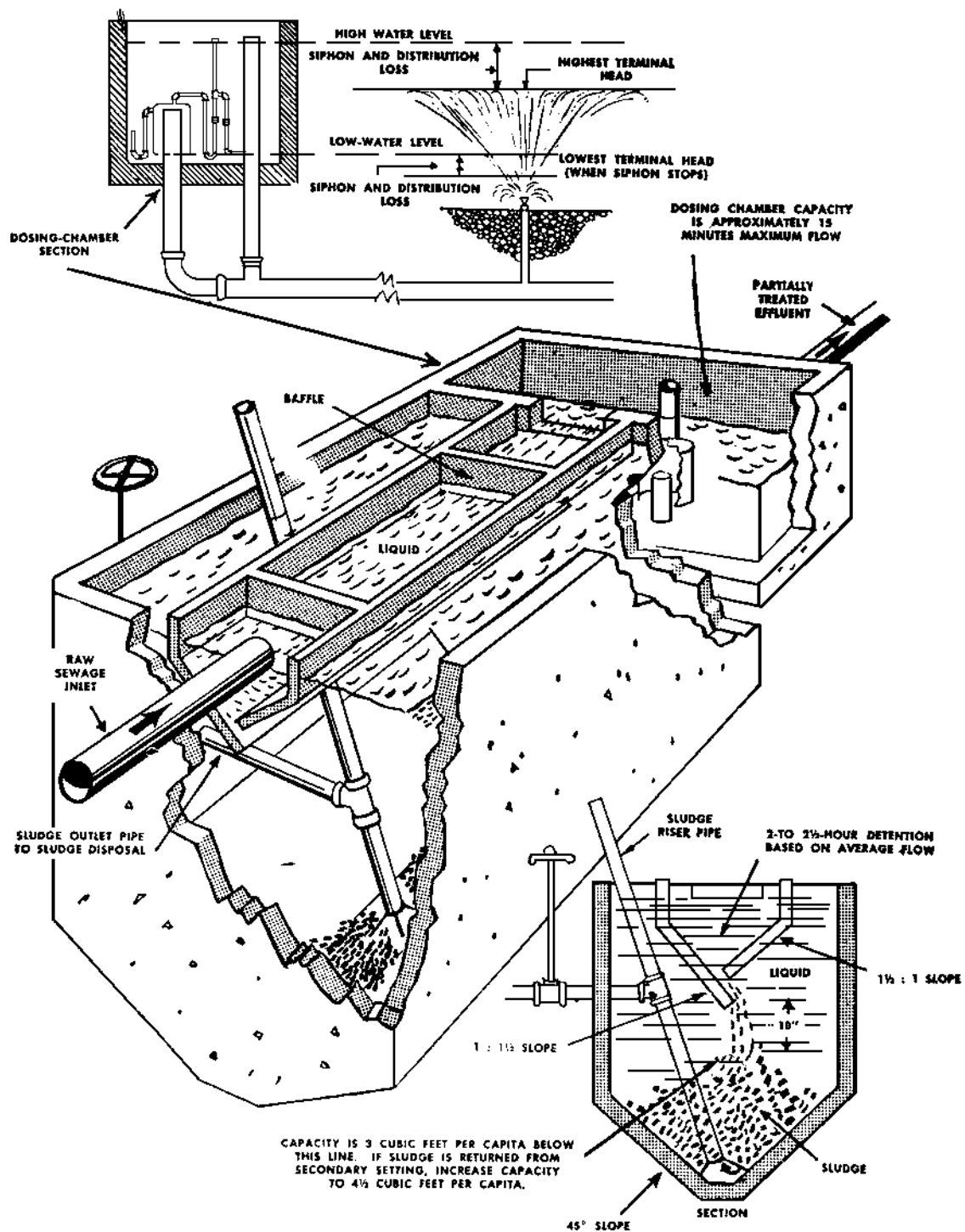


Figure 6-14. Imhoff tank, wood or masonry construction.

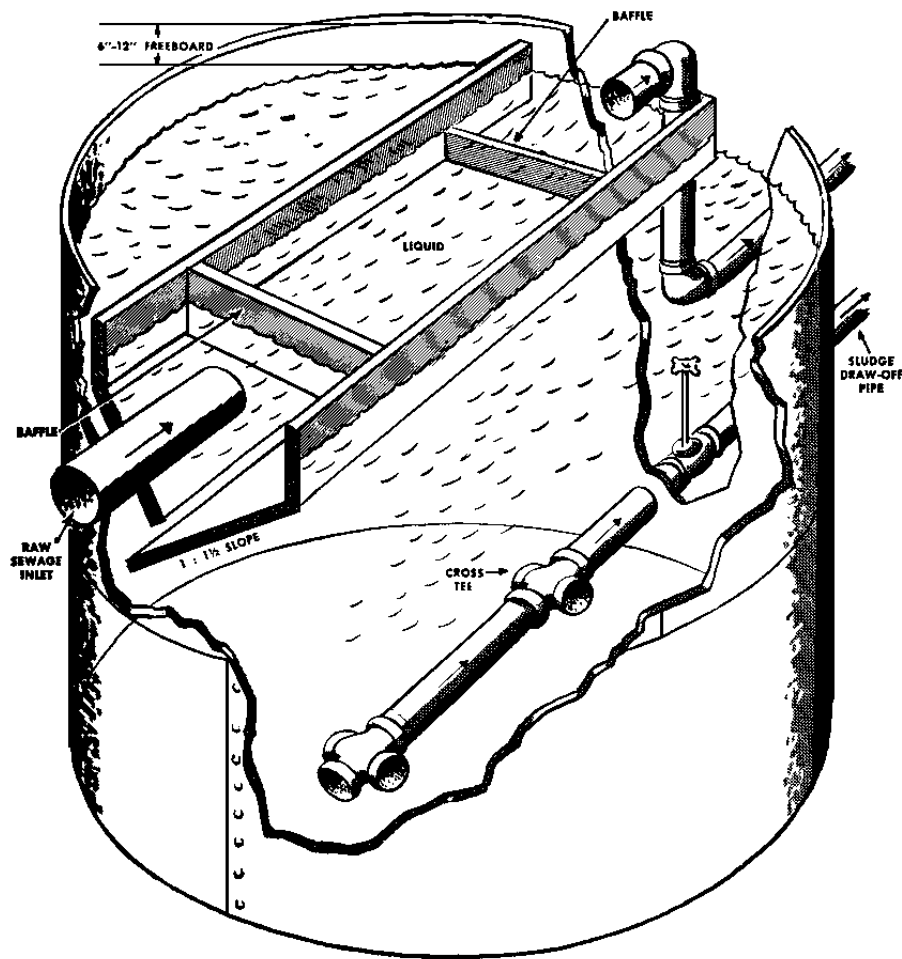


Figure 6-15. Imhoff tank, steel or wood construction.

10-foot head from the high-water level in the dosing tank to the sprinkler-nozzle outlet.

a. Filter material. Crushed stone is the best filter material, but gravel, coke, clinker, broken brick, or slag can be used. To permit maximum voids for passage of sewage and air for ventilation, filter material should be reasonably uniform in size - $1\frac{1}{2}$ - to 3-inch stones are best. The filter layer should be 5 to 8 feet deep.

b. Underdrains and main discharge channels. Underdrains may be either whole or half tile laid with open joints, or a grillage of 2- by 4-inch timber laid on edge. The underdrain system must be constructed so all parts of the filter bed are ventilated.

c. Distributing systems. Settled sewage must be distributed evenly over the filter surface. Rotary distributors generally are used. The force of the sewage leaving the

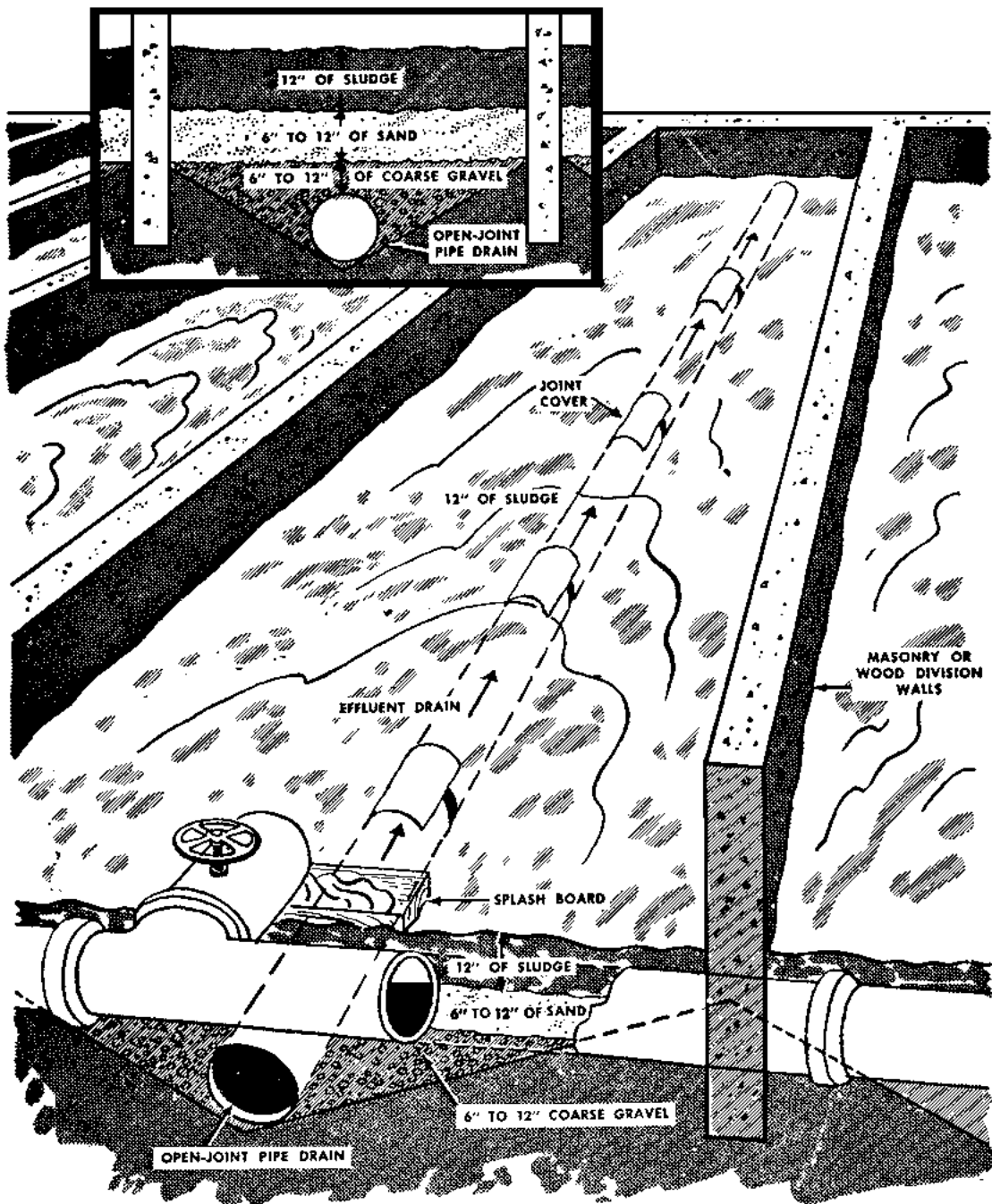


Figure 6-16. Sludge drying bed.

distributor causes it to rotate, spreading the flow evenly over the surface of the bed. Recovery periods should about equal discharge periods.

d. Dosing tanks. A dosing tank with an automatic siphon or an improvised float valve is essential to filter operation. Dosing tanks must be large enough to handle peak flows.

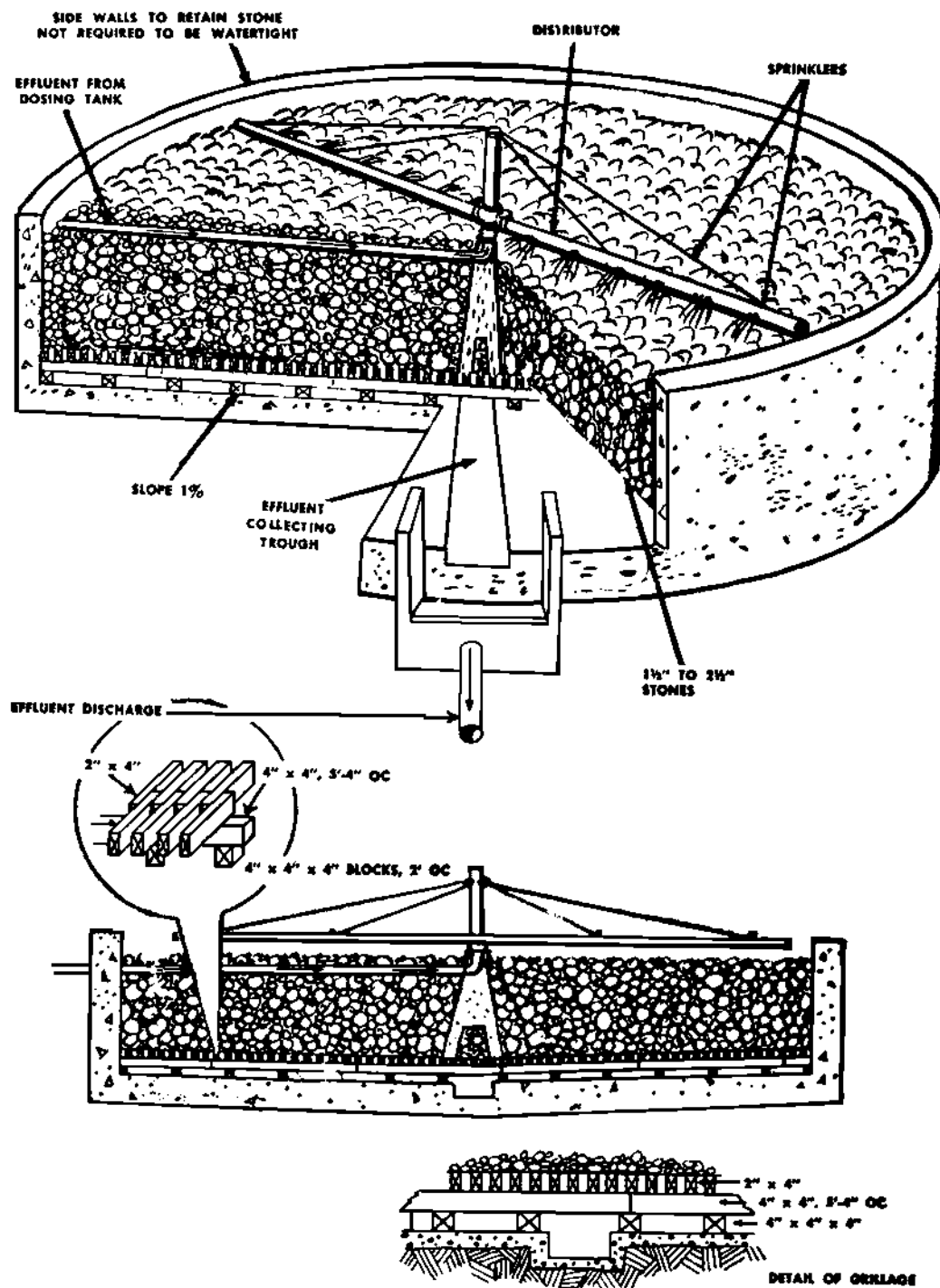


Figure 6-17. Trickling filter, schematic drawing.

Rest periods between doses vary with the flow; under peak flows discharge may be continuous.

6-21. FINAL SETTLING TANK

The effluent from trickling filters should be passed through final settling tanks to remove the bacterial gel which forms on the filter stone and peels off into the effluent. Sludge obtained from final settling tanks is about one-half the volume obtained from primary settling tanks. It can be run directly to drying beds or preferably returned to the digestion tank. Final settling tanks should be large enough to provide a 2- to 2½-hour detention period at the average rate of flow. The sludge should be removed daily to prevent septic action. The slope of the hopper bottom is 1 to 1 or steeper. Side water depth of final settling tanks should not be more than 10 feet. Other details of construction are the same as for plain settling tanks.

6-22. OXIDATION PONDS

The design of oxidation ponds is governed by the following factors:

a. Capacity of the pond is based on a 30-day storage period. At a 25-gcd average flow, the required volume per capita is 100 cubic feet.

b. Only the volume of the pond above a 2-foot depth is considered when the total ponding area is 5 acres or less; when the ponding area is larger, only the volume above a 3-foot depth is considered.

c. Use 50 square feet of surface area per person for ponding areas less than 5 acres and 33 square feet per person for larger installations. For best results, three or more ponds should be used in series. They may be separated by narrow dikes or may be more widely spaced, depending on the terrain and economy of construction. Where it is possible to construct the ponds at different elevations, the flow from one to another should be over a wide and shallow weir to permit maximum aeration and oxidation of the sewage. Where topography permits, a series of weirs, usually called a cascade, is used to secure maximum aeration.

6-23. USE OF DISINFECTANTS

a. Disinfectants, such as liquid chlorine or calcium hypochlorite, may be added to sewage in emergencies to safeguard health and prevent odor and fly nuisances. They are sometimes used during periods of low stream flow when there is not enough stream water for proper dilution. They also may be used when a part of a plant is bypassed during cleaning or breakdown.

b. Chlorine effectively delays BOD and sometimes is used to delay the oxygen demand until the sewage reaches a body of water large enough to provide the oxygen required. It is effective also in killing disease-producing organisms if the contact period and the chlorine concentration are sufficient and if all particles are finely enough divided to permit chlorine contact.

c. Should conditions be such that through failure of power or equipment there is a possibility of contaminating a water supply with raw sewage, provisions should be provided for chlorinating at a rate of 200 pounds per million gallons at the 4-hour rate of sewage flow. In other cases where chlorination is required, provisions should be made for chlorination at a rate of 125 pounds per million gallons at the 4-hour peak rate of sewage flow. The 4-hour peak rate is considered to be 175 percent of the average daily rate of flow. Chlorine can be applied by mechanical chlorinators or contact chambers.

6-24. SEWER MAINTENANCE

Sewer maintenance consists of repair and cleaning.

a. Repair. Sewer repair consist principally of replacing broken man-hole covers and ring assemblies and cracked or crushed lengths of pipe. To install sections of bell-and-spigot clay pipe, chip off half the bell of the length to be inserted and the upper portion of bell on the section of pipe below the gap. Insert and turn the new section so the unchipped half of the bell is on the bottom. Complete the joint mortar or mastic.

b. Cleaning

(1) Stoppages. Clearing stoppages is the most important item of sewer maintenance.

nance. Tree roots often penetrate pipe joints and clog sewers. Large objects and deposits decrease or stop the flow. Sluggish flow, accumulated scum, or sewage backed up in a manhole indicate that repair or cleaning is required.

(2) Methods.

(a) Sewers are cleaned by wooden push rods, flexible steel rods, wooden balls, or flushing (fig 6-18). Push rods 4 feet long are joined together and pushed through the sewer from manhole to manhole. Special tools can be attached to the first rod to clear deposits or cut tree roots. Use of rods is difficult when the distance between manholes is over 300 feet. The flexible steel rod is pushed into a sewer in a manner similar to the push rods. It is rolled when not in use.

(b) Wooden balls of one-half or three-fourths the diameter of the pipe can be used to clean deposits from sewers. They are placed in the sewer and recovered by placing a coarse screen in the manhole downstream. The sewage backed up behind the ball escapes around it at high velocity, scouring out solids deposited in the pipe.

(c) Sewers can be flushed out by damming the outlet in a manhole with a sandbag, and then removing the bag with a rope after the manhole is partially filled. This releases back-up sewage, scouring out deposits. Care must be taken not to back up sewage into fixtures and inlets in buildings.

(d) Discarded fire hose also can be used for slushing. Water pressure makes the hose stiff enough to be pushed through short lengths of pipe.

c. Accident prevention. Sewer gas, methane, hydrogen sulfide, or gasoline and oil drained into sewers may produce explosive mixtures which are easily ignited. Carbon monoxide is particularly dangerous because it is often present in sewers and is not perceptible to the human senses. It may cause a slight headache preceding unconsciousness. Although some of the lighter gases can be removed by opening manholes, the weight of carbon

monoxide is about the same as air and it can be removed only by using a blower. Sewer repair men should work in pairs, one staying above ground to observe and aid the other if necessary. A rope may be tied around a man before going below ground to lift him out if he becomes unconscious. If chemical detectors for carbon monoxide are not available, a caged bird lowered into a manhole may be observed for the effects of gas or a deficiency of oxygen. A strong concentration of carbon monoxide makes a man unconscious almost immediately, and death can be avoided only by artificial respiration. Oxygen deficiency has effects similar to carbon monoxide and is treated in the same manner. It is overcome by opening manholes and forcing in air with a blower.

d. Dangers to health. Sewer workers are exposed to many infectious diseases through skin abrasions and to waterborne diseases such as typhoid fever, paratyphoid fever, and amebic dysentery. Personal cleanliness and immunizations as directed by local medical authorities are the best health protection for workers.

6-25. MAINTENANCE OF TREATMENT PLANTS

a. Cesspools and septic tanks.

Large cesspools and septic tanks should be inspected for depth of sludge. They should be cleaned and the sludge pumped or bailed out when it exceeds one-quarter of the tank depth.

b. Surface-irrigation. Surface-irrigation disposal areas are scraped by machine or by hand when the surface becomes clogged. The extent of clogging is determined by the time required for drainage. A caked surface is cleaned to keep the sewage solids from working down into the bed, and then plowed or harrowed if necessary.

c. Screens. To prevent clogging, screens must be frequently inspected and cleaned whenever necessary. Bar and coarse-mesh screens can be cleaned by raking out the debris, which is then dried, and burned or buried. Small-mesh screens can be changed when they become clogged, since they are usually in removable frames.

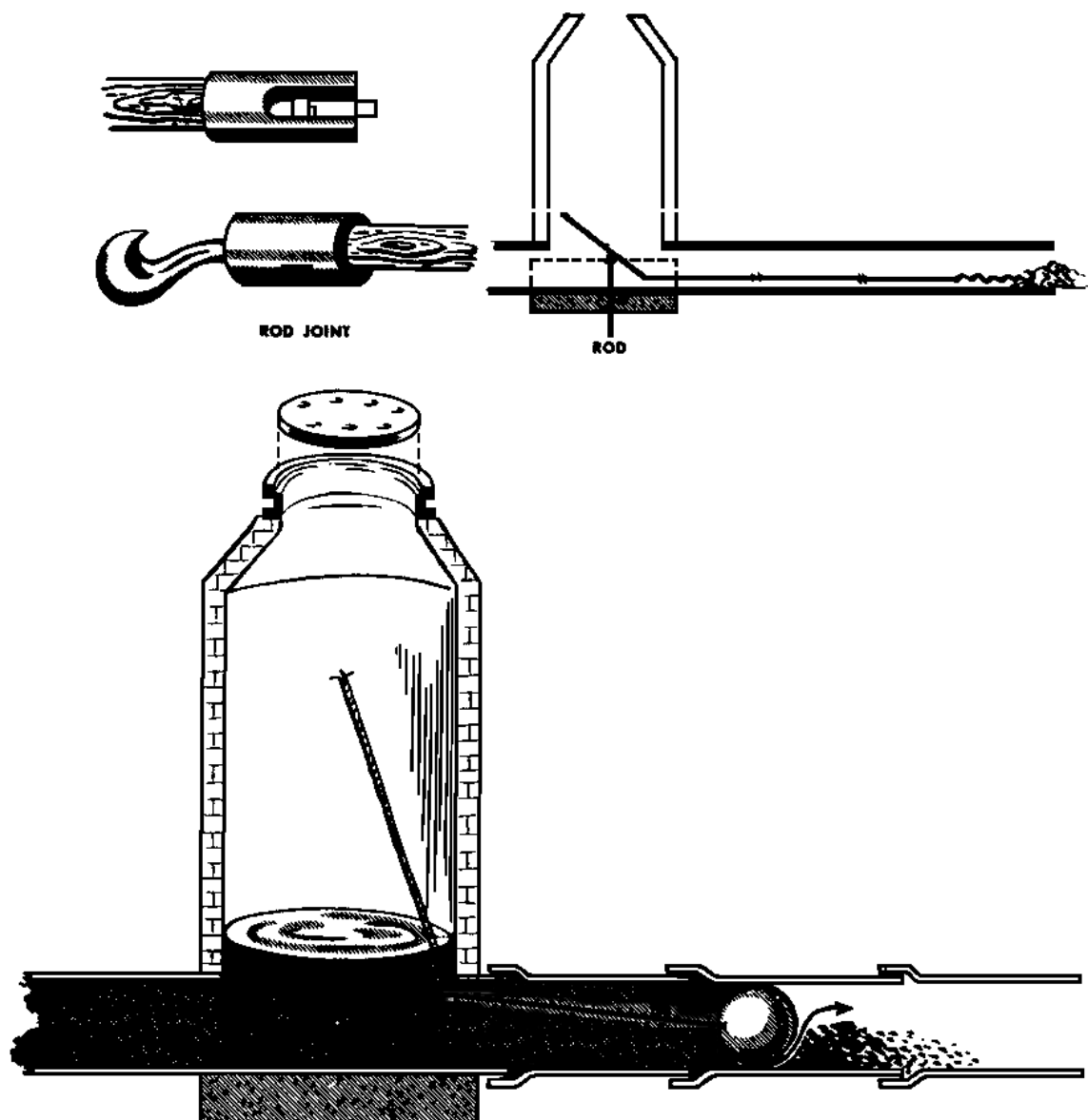


Figure 6-18. Ball and rods used to clean sewers.

d. Plain settling tanks. The sides of plain settling tanks must be kept free of scum. Sides can be washed and cleaned with a rubber-edged squeegee. A scum shovel can be made from a coal shovel bent at right angles to the handle. A skimmer made from $\frac{1}{4}$ -inch wire-mesh screen is also useful. Sludge is drawn off at least once a day, preferably more often. Sludge removal is stopped when sludge becomes thin.

e. Imhoff tanks.

(1) Scum in Imhoff tanks is removed from the flow channel in the same way as from plain settling tanks. The slot is cleaned by dropping a chain through it and dragging the chain along the slot. Sludge is withdrawn frequently in small amounts rather than at long intervals and in large quantities. Ripe sludge is black, nearly odorless, and granular. Brown or gray sludge is not completely

digested and should not be withdrawn. Sludge is withdrawn more frequently in warm weather to provide maximum storage space for winter operation when sludge digestion is slow. The sludge should be kept at least 18 inches below the slot at all times.

(2) The most common difficulty in the operation of Imhoff tanks is foaming or boiling, which causes a violent disturbance and mixing of sludge in the digestion compartment. Foaming may be partially controlled by applying the following methods:

(a) Always keep some digested sludge in the tank.

(b) Break the surface scum by wetting it down.

(c) Push the scum down into the digestion compartment.

(d) Punch 3-inch holes in the scum at 2-foot intervals and apply up to 10 pounds of hydrated lime per 1,000 population daily.

Caution: Too much lime will stop digestion and make conditions worse.

(e) Add enough chlorine to the sewage before it enters the Imhoff tank to provide a residual of 3 ppm at a point near the inlet.

f. Separate sludge digestion tanks. Separate sludge digestion tanks function similarly to the sludge compartment of Imhoff tanks. Raw sludge should be added and digested sludge withdrawn frequently in small amounts. Keeping the scum moist by wetting it down aids digestion. Digestion is aided by controlling feeding, temperature, and optimum pH control.

g. Sludge drying beds. Sludge should be run onto drying beds to a 12-inch depth or to a depth that will

dry in 2 weeks. Sand lost by removal of sludge must be replaced when it is reduced to a thickness of 4 inches. Sludge discharged onto a bed that has not been cleaned does not drain or dry properly.

h. Trickling filters.

(1) Dosing tanks and siphons feeding trickling filters must be kept clean to prevent clogging. Slime is cleaned from distributor nozzles with a stiff brush and sticks and branches are removed. Distributor arms are flushed once a week by opening the end gates. The distributor arms can be raised or lowered to secure even distribution. For cold-weather operation, dosing tanks are tightly covered to prevent freezing. Distributor arms and filter walls can be kept free of ice by a coating of heavy crankcase oil.

(2) Clogging or pooling of trickling filters can be relieved by washing the surface with a hose and moving the stone with iron rods or forks. An application of 8 to 10 pounds of chlorine per 1,000 square feet of filter surface will relieve clogging in some cases.

(3) The fly nuisance, common in warm weather with trickling filters having tight walls, can be controlled by plugging the filter outlet and flooding the filter to drown the fly larvae. However, flooding removes the slime on the filter stone, which overloads the final settling tank and produces a polluted effluent. An alternate method of controlling filter flies is to add enough chlorine to the settled sewage to give a residual of 3 ppm, or to apply 100 pounds of common salt per 1,000 square feet of filter surface. As the life cycle of the filter fly is 7 days, control measures must be taken weekly.

REVIEW EXERCISES

Note: The following exercises are study aids. The figures following each exercise refer to a paragraph containing information related to the question. Write your answer in the space provided below each question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in the back of this booklet. Review the lesson as necessary. Do not send in your solutions to these review exercises.

1. Under what conditions, if any, may untreated sewage be discharged into a body of water? (Para 6-1c)

2. The biochemical oxygen demand (BOD) is the amount of oxygen required to stabilize the decomposable organic matter in sewage by biological action. How is it measured? (Para 6-2b)

3. What minimum flow in cubic feet per second, would be required to dilute the effluent from a partial treatment sewage plant serving a 5000 population installation in an otherwise sparsely populated area? The water below the sewage outfall will not be used for industrial or domestic use. (Para 6-4a, table 6-1)

4. Sewage may receive primary treatment only, or both primary and secondary treatment. What does primary treatment consist of? (Para 6-5a)

5. In connection with sewage disposal, what is meant by secondary treatment? (Para 6-5b)

6. Settleable solids are collected in a primary settling tank, then transferred to a sludge digestion tank. What takes place during the digestion process? (Para 6-6b(1))

7. The effluent from settling tanks may be disposed of, or further treated, in several different ways. If disposal is to be made by irrigation, what soil characteristic is essential to both surface and subsurface irrigation? (Para 6-7a(1), (2))

8. Explain the function of a trickling filter in a sewage treatment plant. (Para 6-5b, 6-7c)

9. What is the main difference between a septic tank and a cesspool?
(Para 6-8)
10. In addition to construction materials, labor, and time, what other essential item must be found available before a waterborne sewer system should be considered. (Para 6-10a(2)b)
11. In designing a waterborne sewer system you have determined that the average flow of sewage from a military installation will be 30 gallons per capita per day (gcd). What design capacity will you use for sewers and channels in the system? (Para 6-11a(1))
12. What size pipe will be required to carry 1,000 gallons of sewage per minute at a minimum velocity of 3.0 feet per second with a ground slope of 0.8 percent?
(Para 6-11b, fig 6-8)
13. What is the velocity in feet per second of an existing 10-inch sewer line on a 0.5 percent slope? (Para 6-11b, fig 6-8)
14. A 12-inch sewer pipe is laid on a 3.5 percent slope. What is its discharge capacity in gallons per minute? (Para 6-11b, fig 6-8)
15. List five situations, of conditions, which would normally require the construction of manholes at certain points along a sewer pipeline. (Para 6-11d)
16. Assume that you have made the soil permeability test outlined in paragraph 6-13a and the water level lowered at the rate of one inch in five minutes. How many acres would be required to dispose of sewage by surface irrigation if you estimate it to be generated at the rate of approximately 240,000 gallons per day? (Para 6-13a, table 6-3)

17. What is the approximate required capacity, in cubic feet, of a plain settling tank for an installation of 12,000 population, if the average flow is 25 gallons per capita per day and you require a 2-hour detention period? (Para 6-16b)

18. What is the reason for installing baffles in septic tanks? (Para 6-18b(2))

19. What is the minimum area in square feet, that should be provided for a sludge-drying bed with drains, for a sewage contributing population of 14,000? (Para 6-19c(1))

20. In a cesspool or septic tank, at what depth of sludge accumulation must it be pumped or bailed out? (Para 6-22a)

LESSON 7

REHABILITATION OF UTILITIES

CREDIT HOURS 1

TEXT ASSIGNMENT. Attached memorandum.

MATERIALS REQUIRED None.

LESSON OBJECTIVE Upon completion of this lesson on rehabilitation of utilities you should be able to accomplish the following in the indicated topic areas.

1. Planning and estimating. Developed a preliminary plan and estimate materials required for the rehabilitation of utilities damaged by demolition or combat action.

2. Water supply. Prepare detailed plans and supervise work involved in rehabilitating existing damaged water supply systems. Developed water distribution systems and priorities, to include the local civilian population.

3. Sewage, garbage, and refuse. Make such plans and arrangements as are necessary to insure that sewage, garbage, and refuse are disposed of in such a manner that they do not result in contamination, disease, or other hazard.

4. Electric power. Plan and execute the rehabilitation of damaged civilian electric power systems in combat or communications zones.

ATTACHED MEMORANDUM

7-1. INTRODUCTION

a. This lesson covers the general problems encountered in rehabilitating utilities damaged by demolition or combat action and suggests solutions for these problems. The primary concern is the rehabilitation of municipal utilities. However, in certain cases it is also advantageous to rehabilitate small private utilities, such as those connected with industrial and manufacturing plants.

b. The material in this lesson is confined to water supply, sewerage systems, garbage and refuse disposal, and electric power. Detailed planning to determine materials, equipment, troops, priorities, and the like can only be made for specific operations.

7-2. EXTENT OF WORK

The extent of rehabilitation by the Army is governed by two factors.

a. Immediate military need. The first consideration in rehabilitation is the need of our own troops. Early rehabilitation of such facilities as port and transportation systems, industrial plants, and repair shops is vitally important to the military forces. The supply of water and power to repair and operate these facilities must be provided as quickly as possible. The work can usually be done most efficiently by local civilians familiar with the systems.

b. Civilian needs. Although civilian authorities are responsible for all rehabilitation

not essential to the military effort, the Army must be prepared to furnish those utilities necessary to prevent civilians from becoming a burden to the Army through outbreak of disease, uncontrolled mass migrations, or other economic problems. If civilians abandon a city before it is occupied, the selection and number of persons permitted to return depend on their value to the military effort and on the available housing and sanitation facilities.

7-3. PLANNING

Normally, initial planning for rehabilitation of utilities is made before physical reconnaissance. Basic factors of preoccupation planning are as follows:

a. Reconnaissance data. All available information regarding the area to be occupied should be gathered and pertinent data extracted before the actual occupation. Sources of information are maps, aerial and ground photographs, plans and specifications, publications, intelligence reports, and interviews with personnel familiar with the area. Preparation of the reconnaissance report is simplified by using a form applicable to utilities.

b. Damage inventory. An estimated damage inventory is prepared from reconnaissance data, showing the percent of total destruction requiring all new material, the percent of partial destruction which can be repaired by use of local material and cannibalization, and percent of minor damage.

c. Repair estimates. Priorities for, and extent of, repairs are based on their value to military operations. Estimates of troops, equipment, and material needed to make necessary repairs should be detailed. Plans for delivery of material and equipment are based on and coordinated with the priorities schedule established for the repair work. Provision must be made for a stockpile of material and equipment in the occupied area.

7-4. BASIC PRINCIPLES OF REHABILITATION WORK

Some of the more important basic principles for wartime rehabilitation work are as follows:

a. Substitution. Under some circumstances, damaged utilities, particularly foreign systems, may be repaired more efficiently to meet wartime requirements by modifying the original system and substituting materials and equipment. Extent of damage, possibilities of cannibalization, and available local stocks of repair parts and materials are governing factors.

b. Expedient repair. If time is the limiting factor in the repair of certain utilities, completion of the job is more important than economy of labor, materials, and equipment.

c. Improvised repair. In making improvised repairs, any suitable material or equipment at hand is used to meet immediate needs. Improvised repairs are improved as time and supplies permit.

d. Cannibalization. Utility systems having identical or similar units may be restored sufficiently to meet military requirements by robbing parts from some damaged units to repair others.

e. Use of civilians. Civilians familiar with local installations are used to operate local systems, assist in repair, furnish maps and charts, and locate warehouses, stockpiles, and the like whenever possible. Their value in this respect cannot be over-emphasized. Civilians employed for this work must be controlled by military authorities to prevent rehabilitation beyond immediate military necessity. They must be carefully selected to avoid possible sabotage.

f. Local materials and supplies. Local materials are used whenever possible so shipping space can be used for more essential items.

7-5. MINES AND BOOBYTRAPS

Mines and boobytraps are anticipated in any area previously held by the enemy. When planning rehabilitation work, it is reasonable to assume that any installation will be mined or boobytrapped. Therefore, the installations, surrounding area, and access roads must be checked by trained personnel for mines and boobytraps. Civilians can aid in detecting boobytraps by recognition of irregularities.

7-6. WATER SUPPLY SYSTEMS

a. Effects of damages.

(1) Damaged water supply systems produce conditions favorable to the outbreak and spread of disease. Damaged water mains are subject to contamination, and lack of water for cooking and hygienic purposes results in the use of untreated sources. The more common diseases attributed to contaminated water are typhoid fever, cholera, and dysentery. Diarrhea may also be caused by contaminated water. An epidemic of any of these diseases seriously hampers military operations.

(2) Damaged water supply systems may prevent the Army from using industries which would aid the military effort, but which are dependent on a supply of water for operation.

b. Procedure. The rehabilitation of a water system requires--

- (1) Determining military and minimum civilian water requirements.
- (2) Establishing a temporary supply, pending restoration of service through the normal distribution system.
- (3) Estimating the damage to the normal system.
- (4) Planning the rehabilitation of the normal system.
- (5) Requisitioning and storing materials and equipment, and securing labor needed.
- (6) Making the repairs.
- (7) Testing and disinfecting the system before returning it to use.

7-7. CIVILIAN WATER REQUIREMENTS

a. Domestic use. For small communities or towns, a supply of potable water for drinking and cooking is usually all that must be provided. For large communities and cities, water must also be supplied for personal hygiene and waterborne sewage disposal. Minimum requirements to meet these needs are as follows: 1/3 gallon per capita per day (gcd) for drinking only; 4 gcd without a piped system or waterborne sewage disposal; 14 to 20 gcd with waterborne sewage disposal.

b. Industrial use. When estimating

water requirements for an area, the supply of water to industries is limited to those which can directly aid the military operation.

c. Fire protection. An adequate and reliable supply of water is necessary for fire protection. If the available rate of flow does not meet fire protection demands, independent storage tanks or sumps must be located near plants and facilities which have a military value. Basements of bombed-out buildings may be used to store water to meet firefighting requirements. Salt water may be used for firefighting.

7-8. TEMPORARY SUPPLY TO CIVILIANS

Troops advancing into a damaged area carry water and purification equipment to meet their own needs, but not enough to supply a large number of civilians. Therefore, if the civilian water system is nonproductive, civilian requirements must be temporarily provided by the Army until the normal system is rehabilitated. This temporary supply may be provided by specially equipped units, such as the engineer service teams, or by making temporary local arrangements. In either case, a water source must be selected and a distribution system set up.

a. Selection of source. It is usually feasible to use the normal source. However, if extensive engineering works in the system are destroyed, it may be more practical to select a new source. Operators of local systems can assist greatly in selection.

b. Treatment. Water for temporary civilian use must be treated to prevent the spread of waterborne diseases. Normally, disinfection with chlorine meets these requirements. When amebic cysts are suspected, moderately clear water with a pH of 7 or less can be disinfected by adding enough chlorine to produce a residual slightly greater than 2 ppm after a 30-minute contact period.

c. Distribution methods.

(1) Water distribution points.

(a) Minimum civilian requirements

of 1/3 gpd can be met by setting up temporary water distributing points from which civilians may draw their water. If a source is available at each distributing point, the problem is relatively simple. However, water must ordinarily be transported from the source to the distributing point in tank trucks or cars or in temporary pipelines.

(b) If water is available in certain portions of the damaged system, hydrants on the edge of the damaged area may be used to fill tank trucks which carry the water to residents of the damaged area. Users draw water directly from the trucks or from tanks set up at convenient points.

(2) **Limited normal service.** The distributing-point supply system should be abandoned as soon as the normal system is repaired sufficiently to provide minimum needs.

7-9. PLANNING FOR REPAIR OF NORMAL SYSTEM

The thoroughness and detail involved in planning rehabilitation of the existing system determine the speed and effectiveness of repair. Local technical personnel, labor, and materials, and cannibalization of existing equipment, must be used to full advantage. All records of local systems, such as distribution-system maps, valve records, legend of symbol, and comprehensive maps, aid in rehabilitation. Symbols are shown in figure 7-1.

7-10. DAMAGE TO BE EXPECTED

a. Sources. Wells are usually partially filled with debris and walls are damaged. Damage to springs or galleries is usually confined to the collecting system.

b. Storage facilities.

(1) Elevated tanks are generally damaged beyond repair if toppled from high supports.

(2) Normally, small reservoirs are totally destroyed, while damage to large reservoirs is confined to dam control works, intake structures, walls, levees, or dams.

c. Distribution systems. Damage to distribution systems is normally confined to pumps, valves, aqueducts,

and mains. Aqueducts and mains may be broken in one or more places. Hidden leaks may occur at some distance from the point of explosion, and may flow unnoticed into sewers and other underground channels. When located, they are repaired or bypassed. Before personnel enter a crater, overhanging debris should be removed and earth surrounding the crater should be inspected for stability, as water from leaks may cause the sides of the crater to cave in.

d. Contamination.

(1) The retreating enemy may deliberately contaminate water supply systems by placing bone oil, refuse, bodies, lubrication oils, or other materials in wells, springs, reservoirs, tanks, or the distribution system.

(2) A water system is easily contaminated when water mains and sewers which are close together are fractured. If the water mains and sewers are on a steep gradient, sewage may enter the water mains with enough head to flow to the consumers' taps below. Contamination may result when pressure within the system is reduced by broken mains, heavy draft for firefighting, valve closures, and supply failures which often occur during enemy attack. Contamination may also be caused by filth entering open mains through open ends or fractures during repair operations.

7-11. MATERIALS AND EQUIPMENT

a. Pumps. Pumps are selected to meet the head and discharge requirements of each installation. The type and number of pumps vary with the source of supply and the system to be operated. Tables 7-1 and 7-2 give the capabilities of deep-well and surface pumps based on 24-hour operation. Allowances must be made for time lost by shutdowns. If use of wells over 200 feet deep is anticipated, deep-well pumps must be selected carefully, as those sent overseas have a maximum head of 250 feet or less.

b. Well-drilling machines. All wells 8 inches or less in diameter can be drilled with

ITEM	JOB SKETCHES	SECTIONAL PLATS	VALVE RECORD INTERSECTION SHEETS	COMPREHENSIVE MAP AND VALVE PLATS
3" AND SMALLER MAINS	-----	-----	-----	-----
4" MAINS	-----	-----	-----	-----
6" MAINS	-----	-----	-----	-----
8" MAINS	-----	-----	-----	-----
LARGER MAINS	-----	-----	-----	-----
VALVE	SIZE NOTED 	SIZE NOTED 	12" 36" 36" 	12" 36" 36"
VALVE, CLOSED				
VALVE, PARTLY CLOSED				
VALVE IN VAULT				
TAPPING VALVE AND SLEEVE				
CHECK VALVE (FLOW →)				
REGULATOR				
RECORDING GAGE				
HYDRANT 2"-3 1/2" NOZZLES				
HYDRANT WITH STEAMER				
CROSSOVER (TWO SYMBOLS)				
TEE AND CROSS				
PLUG, CAP, AND DEAD END				
REDUCER				
BENDS, HORIZONTAL				
BENDS, VERTICAL				
SLEEVE				
JOINT, BELL-AND-SPIGOT				
JOINT, DRESSER TYPE				
JOINT, FLANGED				
JOINT, SCREWED				

Figure 7-1. Distribution system symbols.

TABLE 7-1. Capabilities of Deep-Well Pumps

Volume (gpm)	Head (ft.)	Gallons per day
30	250	43,200
60	250	86,400
200	200	288,000
150*	100	216,000

*Pump, sump, pneumatic.

TABLE 7-2. Capabilities of Pumps Used for Surface Sources

Volume (gpm)	Head (ft.)	Gallons per day
55	50	79,200
100	100	144,000
166	25	239,040
200	350	288,000
480	300	691,200
500	20	720,000

standard Army equipment. Special equipment is required for larger wells.

c. Purification plants. The only new equipment normally required to rehabilitate purification plants is pumping units and chlorination equipment. Coagulants can be introduced into the water with a device similar to the expedient chlorinator.

d. Storage facilities. Normal construction materials and equipment are needed for repairing reservoirs, dams, tanks, and galleries.

e. Distribution systems. Pumps, valves, mains, and aqueducts usually require repair. All pumping equipment should be brought in. Stocks of pipe and valves are usually on hand locally but they may vary considerably in size. Unless better information is available, a reasonable allowance to be brought in, based on miles of piping and population served, is as follows:

(1) **Pipe.** Enough pipe is required to repair one 30-foot break per mile of pipe in system. If pipe size is not known, pipe size selected is determined by anticipated volume of pumps.

(2) **Valves.** One gate valve for every 5 miles of system piping, one 2-

inch threaded valve for each 4,000 population, and suction and discharge valves for pump installations are necessary.

(3) **Adapter sleeves or couplings.** Two sleeves or mechanical couplings for each open pipeline break per mile and two per mile for miscellaneous repair are needed.

(4) **Tees.** One tee of correct size for each 5 miles of piping is required.

(5) **Elbows.** One 45-degree and one 90-degree bend for each 3/4 mile of piping are required.

(6) **Wooden plugs.** Breaks may be stopped temporarily with wooden plugs.

(7) **Dispensing units.** Until the normal distribution system is repaired, provisions must be made for dispensing water into hand-carried containers. A 2-inch header with four 3/4-inch taps on each side spaced 10 feet apart serves 8,000 to 10,000 persons with an emergency supply. Units should be installed at points where water is available under pressure. These units are usually made up to meet local needs.

(8) Tanks.

(a) **Requirements.** Tanks are used advantageously where continuous pumping operation is not practical. Enough tanks must be set up to provide 1/2 gallon of water per capita for 5 percent of the population of cities. If sources are polluted, storage tanks are also required for treatment and filtered-water storage.

(b) **Types.** Tanks are usually standard prefabricated bolted steel or standard knockdown wooden tanks.

7-12. REPAIRS

As soon as the tactical situation permits, work should be started on restoring water supply, since water supply systems have a higher priority in rehabilitation than other utilities. Suggested procedures for repairing municipal water supply systems are given below.

a. Location of pipes and valves. Pipes and mains, valves, and pumping stations can be located from existing maps. Local tech-

nicians can assist greatly in interpreting maps and data. Mines detectors can be used to locate mains and valves.

b. Repair or mains.

(1) **Repair difficulties.** Water mains may be difficult to repair for the following reasons:

(a) Debris and craters may block the approach for repair equipment.

(b) Valves may be difficult to locate because of debris or because reference points are destroyed.

(c) Craters may be filled with debris and water.

(d) Subsoil under the main may be loosened by explosion or flooding.

(2) **Repair equipment.** Standard engineer construction equipment and materials, such as power excavators and ditchers, compressors with accessories, pumps, dozers and shovels, pipe-cutting and pipe-joining equipment, and shoring and sheathing are usually adequate for most main repairs.

(3) Materials.

(a) Mechanical joints and couplings are generally desirable because they are quickly and easily installed and because they resist vibration and settlement.

(b) Cast-iron pipe with mechanical couplings, iron or steel pipe may be used for making repairs. Steel pipe is preferable to cast-iron pipe because it is stronger and lighter, can be fabricated in longer lengths, has fewer joints, and is easier to transport and handle. Fire hose may also be used for temporary bypasses.

(4) **Temporary repairs.** Temporary repairs are made to control water wastage, maintain essential flow, and permit the reopening of valves. These repairs may consist of plugging or capping fractured mains or shunting water around breaks with fire hose connected to the fractured pipe or fire hydrants. However, permanent repairs should be made as soon as possible because bypasses interfere with traffic, are likely to freeze in cold weather, and may not provide sufficient supply.

(5) **Testing.** Repaired lines should be tested for leaks under slightly

more than working pressure before they are covered. To avoid tying up traffic by repairing long sections of a system, it may be necessary to make repairs a block at a time. In this case, the line can be capped and tested by blocks.

7-13. DISINFECTION

The importance of disinfecting water systems before returning them to service cannot be overemphasized. During disasters when the system is most likely to become contaminated, there may be a tendency to overlook disinfection.

7-14. SEWAGE AND GARBAGE

a. Effect of damage. Human wastes, garbage, and refuse must be properly disposed of in occupied areas to protect troops and to prevent epidemics among civilians. If sewage enters a water supply, an outbreak of intestinal diseases such as typhoid, cholera, dysentery, and diarrhea is almost certain to follow. To prevent such outbreaks, which hinder military operations, the Army may have to rehabilitate existing sewer systems and aid in disposing of garbage and refuse.

b. Army responsibilities. In sewer rehabilitation, the Army provides a minimum of equipment and materials, and only enough troops for supervisory duties. Highly populated urban areas such as apartment-house districts depend almost entirely on water-borne sewage disposal systems, while smaller communities can use temporary latrines. Job priorities for the overall sewer rehabilitation plan are based largely on the density of population served.

c. Classification of sewage. Sewage is divided into three classifications, according to its source. These classifications are given different degrees of consideration in rehabilitating a disposal system.

(1) Domestic sewage comes from residences, institutions, and business buildings and must receive first consideration in the rehabilitation program.

(2) Industrial waste is the liquid resulting from manufacturing or industrial pro-

cesses. Disposal of these wastes is the responsibility of the plant from which they originate.

(3) Storm sewage is the runoff during or immediately after storms. Disposal of storm sewage is considered only when it may hinder military operations by flooding critical areas.

d. Classification of sewerage systems. Sewerage systems are classified according to the type of sewage they carry. Sewers carrying domestic sewage and/or storm sewage or industrial waste are combined sewers. Those carrying only domestic sewage are sanitary sewers. Storm sewers are those which carry only storm sewage and surface runoff.

e. Procedure. The rehabilitation of a sewage disposal system requires--

(1) Choosing and establishing priorities for the areas in which waterborne sewage is essential.

(2) Planning the rehabilitation of sewage systems within the selected areas.

(3) Estimating the damage to sewers and sewage disposal systems.

(4) Requisitioning and storing materials and equipment needed.

(5) Making the repair.

7-15. SEWER DAMAGE TO BE EXPECTED

a. Sewers. Most damage to sewers results from bombing or artillery fire and may occur anywhere in the system. Deliberate demolition by the enemy is usually limited to junction manholes or large mains. Stoppages caused by debris being blown and washed into sewers can be expected.

b. Pumping stations. The enemy may destroy pumping stations deliberately because they are key points, are more accessible, and are most difficult to repair. They are not likely to be damaged seriously by bombs or artillery fire since they offer a relatively small target.

c. Treatment units. Treatment units may be damaged by the demolition of machinery and other key equipment. They are not profitable bombing targets.

d. Cesspools and septic tanks.

Damage to cesspools and septic tanks from sabotage or bombing is relatively unimportant. Destruction of one would effect only one or a small number of properties. Their wide dispersal provides a large measure of safety.

7-16. MATERIALS AND EQUIPMENT

a. Pumps.

(1) Portable, skid-mounted, centrifugal, gasoline-engine-driven pumps are the most suitable type for use in rehabilitating sewerage systems. They must be of nonclog design capable of handling unscreened sewage. Pumps with 4-inch intake and discharge are the most adaptable, since they can be used for draining craters, pumping around blocked sections of sewers, and temporarily replacing damaged pumping stations. As many of these units can be installed as is necessary to handle the sewage, but if large amounts of sewage are anticipated, larger pumps should be requisitioned.

(2) Some smaller diaphragm pumps should be included to move small amounts of sewage or to drain numerous small craters. An estimate to the percent of existing pumps which can be restored by cannibalization can be made from reconnaissance data.

b. Pipe and materials. Normal sewer construction requires clay products, which are usually available locally. If no sewer pipe is available locally, masonry or timber can be substituted. Cement is brought in for masonry work. A limited amount of steel pipe and hose for pump suction and discharge lines used in bypassing, draining craters, and the like is brought in. Pipe less than 4 inches in diameter should never be used for sewage.

7-17. EMERGENCY REPAIR

a. Sewers. Sewers are the most essential item in a sewage disposal system. If the situation is critical, service can be restored temporarily by pumping from an upstream manhole, around the damaged section, and into a downstream manhole. If the sewer is

completely stopped or badly damaged, an open channel can be built. Where storm and sanitary sewers are separate, it may be possible to divert sanitary sewage through a storm sewer to a suitable outlet.

b. Treatment plants. If treatment plants are severely damaged, it may be necessary to bypass them. Settling and digestion tanks and filters can usually be repaired with standard construction materials. Sludge beds are practically indestructible. Machinery must be repaired by cannibalization or improvised methods. If compressed air is used in an activated sludge process, replacement of air compressors is difficult. However, the activated sludge plants can be operated as sedimentation or septic tanks. Such treatment, together with chlorination, gives a reasonable degree of purification.

7-18. GARBAGE AND REFUSE DISPOSAL

a. Problems. During wartime, refuse disposal in a city be interrupted by the enemy taking away or damaging the collecting vehicles and equipment used at sanitary fills. Incinerators are relatively unimportant as compared to other utilities and may not be damaged.

b. Disposal. Garbage and refuse is usually disposed of by incineration, sanitary fills, dumping, sale, or contract.

c. Plan of rehabilitation.

(1) All available transportation is listed and allocated.

(2) Railway sidings are designated for daily shipment of garbage and refuse to fills or incinerators, and river or ocean barges are allocated for hauling and dumping into the ocean or other suitable body of water.

(3) Garbage-disposal contractors are instructed to use horse-drawn vehicles if enough motor vehicles are not available.

(4) Equipment or transportation should not be requisitioned until a survey is made of requirements.

(5) Householders must burn or bury their own refuse until adequate disposal facilities are rehabilitated.

A common burial pit can be used for apartment-house districts.

7-19. ELECTRIC POWER SYSTEMS

The following paragraphs describe policy for rehabilitating damaged civilian electric power systems in combat or communications zones. All military services coordinate their electric power requirements through the Corps of Engineers. Civilian agencies are responsible for restoring and maintaining the electric service to fulfill civilian needs. Civilian labor is used to meet these requirements.

7-20. PRIORITY OF POWER ALLOCATION

Power is generally provided according to the following priority system:

a. Essential military needs, such as hospitals, ports, and shops.

b. Essential public needs, such as water pumping, hospitals, and necessary sewage pumping.

c. Industries beneficial to the military effort.

d. Industries essential to civilian health and welfare.

e. Nonessential military requirements, such as troop housing.

f. Civilian requirements.

7-21. RECONNAISSANCE

a. Small isolated plants of factories or large buildings should be reconnoitered in addition to the major plants. Often these plants escape enemy demolition because they are small and widely dispersed, and may furnish enough power to meet military requirements, since these requirements do not need the total output of the major system.

b. Initial reconnaissance is limited to obtaining information on enough equipment to supply immediate military demands. Complete reconnaissance is the responsibility of civilian agencies.

c. To aid in ordering repair parts and in determining equipment which may be shifted to another location to replace similar pieces of

destroyed equipment, the complete name-plate data are secured for each piece of equipment. The extent of damage to each piece of equipment is determined and the time and material required for repair is estimated.

d. Information regarding the extent of damage and repair necessary can be obtained from civilians. However, the Army must control such civilian aid to curb tendencies toward maintaining civilian standards in repairing equipment. Maps and charts of transmission grids and distribution lines, showing location of substations, switching stations, generating plants, transformers, and oil circuit breakers, are useful in the initial stages of rehabilitation.

Caution. All circuits must be thoroughly examined for enemy mines before they are energized.

7-22. POWER DAMAGED TO BE EXPECTED

a. Power centers. Damage is usually concentrated at the power centers and particularly at power sources. Typical type of damage to be expected include-

- (1) Punctured steam boilers.
- (2) Smashed control equipment.
- (3) Broken turbine blades.
- (4) Damaged speed- and load-control governor of turbines.
- (5) Broken penstocks supplying hydro-electric stations.
- (6) Shattered insulators and bushings.

b. Transmission and distribution lines. Transmission and distribution lines normally receive little damage in comparison with power stations.

c. Extent. Extent of damage to electric power systems for preliminary planning can be based on the following average estimates:

Installation	Damage
Power stations	40%
Transformer stations	35%
Switch gear	30%
Transmission and distribution lines	5%
Transformers	20%
Busses and connections	40%

7-23. MATERIALS, EQUIPMENT AND PERSONNEL

Initial military needs are supplied by portable generator sets. In rehabilitating electric power systems, cannibalization is the main source of supply. General items of equipment such as wire, insulators, and hardware necessary to rehabilitate power systems supplying facilities needed immediately by the Army (dock cranes or other harbor installations) should closely follow the assault troops. Material and equipment for use in later stages, or of less immediate importance, should not be shipped until physical reconnaissance is completed. Personnel should be provided to make the reconnaissance as soon as the tactical situation permits. Some new supplies and equipment are always needed. A small number of key personnel are required to operate and perform first and second echelon maintenance on portable generator sets installed to furnish electric power for military and essential civilians needs and to operate and maintain transmission and distribution lines. Tables 7-3, 7-4, and 7-5 give approximate key personnel requirements.

7-24. RESTORATION PROCEDURES

a. Full advantage is taken of repair part stocks which each power plant maintains. Help is obtained from former civilian plant employees. Key men usually report voluntarily and solicit the aid of others.

b. Oil from damaged transformers must be filtered before being reused. Motor oil is not satisfactory for transformer use. A highly refined mineral oil free from moisture of impurities must be used. The transformer must be thoroughly dried before filling with oil.

c. Wrecked buildings must be cleared of unstable walls and other hazards to protect repair personnel.

d. Holes in the tanks of the transformers can be patched by welding. Bushing can be

Table 7-3. Key Personnel Requirements for Operation and Maintenance of Portable Generator Sets

Civilians (labor)	Basics ¹	Engineers, operating	Generator and related operators	Electricians ²	
1	0	2	2	$\frac{1}{10}$	50- to 100-kw generator set
2	0	3	2	$\frac{1}{6}$	100- to 200-kw generator set
2	1	4	4	$\frac{1}{4}$	200- to 400-kw generator set
2	2	4	4	$\frac{1}{3}$	400- to 600-kw generator set
3	2	4	4	$\frac{1}{2}$	600- to 800-kw generator set
4	2	4	4	$\frac{3}{4}$	800- to 1,000-kw generator set
4	4	4	4	1	1,000-kw and larger plants

¹Competent civilian personnel may be used if available.
²One electrician can supervise ten 50- to 100-kw units, six 100- to 200-kw units, four 200- to 400-kw units, and so on.

Table 7-4. Key Personnel Requirements to Operate and Maintain Distribution Lines Less than 15-kv

	Length of line (miles)								
	0 to 50	50 to 100	100 to 200	200 to 300	300 to 400	400 to 500	500 to 600	600 to 800	800 to 1,000
Foremen, construction -----	1	1	2	3	4	5	6	7	8
Linemen, power -----	3	4	8	12	16	20	24	28	32
Truck drivers (heavy) -----	0	0	0	1	2	2	2	2	3
Truck drivers (light) -----	1	1	2	3	4	5	6	7	8
Basics* -----	1	2	4	6	8	10	12	14	16
Civilians (labor) -----	1	2	4	6	8	10	12	14	16

* Competent civilian personnel may be used if available.

Table 7-5. Key Personnel Requirements to Operate and Maintain 15-kv to 90-kv Transmission Lines

	Length of line (miles)								
	0 to 50	50 to 100	100 to 150	150 to 200	200 to 250	250 to 300	300 to 350	350 to 400	400 to 500
Foremen, construction -----	1	2	3	3	4	4	5	6	8
Linemen, power -----	4	8	12	12	16	16	20	24	24
Truck drivers (heavy) -----	1	2	3	3	4	4	5	6	6
Truck drivers (light) -----	0	0	0	1	1	2	2	2	3
Basics* -----	3	6	9	9	12	12	15	18	18
Civilians (labor) -----	3	6	9	9	12	12	15	18	18

* Competent civilian personnel may be used if available.

improvised and the transformers returned to service after the lost transformer oil is replaced. If the coils are damaged materially, it is not feasible to repair them. To test the coils and core of a transformer, apply approximately one-fourth of the rated voltage to the low-tension coils, and observe the transformer for 15 minutes. A fault is indicated by abnormal heat, noise, or smoke.

e. Remote-control equipment is easily damaged. However, a plant may be used without the remote-control

equipment by operating machines and switches manually.

f. Damage to transmission lines, usually caused by artillery fire or bombing, is spasmodic, whole stretches of good line being found between damaged sections. Towers are often repairable or new ones can be improvised from available structural pieces. Conductors are spliced together using wire-rope clips. Missing conductors can be replaced by robbing unimportant lines.

REVIEW EXERCISES

NOTE: The following exercises are study aids. The figures following each exercise refer to a paragraph containing information related to the question. Write your answer in the space provided below each question. When you have finished answering all the questions for this lesson, compare your answers with those given for this lesson in the back of this booklet. Review the lesson as necessary. Do not send in your solutions to these review exercises.

1. Under what circumstances would the Army in combat, rehabilitate utility systems for the local civilian population? (Para 7-2b)

2. An estimated damage inventory is prepared from gathered reconnaissance data. What are the three categories into which damage is classified? (Para 7-3b)

3. When may it be appropriate to perform a utilities rehabilitation project without regard to economy of labor, materials, and equipment? (Para 7-4b)

4. When preparing to rehabilitate a damaged water pumping station in an area previously occupied by the enemy, what precautionary measure should you take? (Para 7-5)

5. Evidence of an outbreak of cholera in a recently occupied city in enemy territory would lead you to suspect what type of utilities problem? (Para 7-6a(1))

6. For planning purposes, what is the minimum amount of water you must provide for a small civilian community for drinking purposes only? (Para 7-7a)

7. What is the minimum daily water requirement for a city of 100,000 inhabitants, the city having waterborne sewage disposal? (Para 7-7a)

8. In planning of the water requirements for a city about to be occupied, what criteria governs the amount of water to be allowed for industries? (Para 7-7b)

9. Upon occupation of a war damaged city you find it necessary to make arrangements for temporary supply of water by tank trucks to distributing points in the city. At what specific point in the water supply system rehabilitation is the tank truck delivery discontinued? (Para 7-8c(2))

10. You are planning the rehabilitation of a water distribution system in an area you are about to occupy. All you know is that there is 12 miles of pipe in the system and it has undergone a normal amount of damage. How many feet of pipe do you estimate you will need to repair this system? (Para 7-11e(2))

11. In the rehabilitation of a damaged water supply system, what very important action must you take in addition to the repair or replacement of the damaged parts? (Para 7-13)

12. Sewage is classified according to its source as domestic sewage, industrial waste, or storm sewage. Which of the three must receive first priority in rehabilitation of a disposal system? (Para 7-14c)

13. Sewerage systems are classified according to the type of sewage they carry. Name the three classes and give the type of sewage each carries. (Para 7-14d)

14. What is the minimum size (diameter) of pipe that should be used for sewage? (Para 7-16b)

15. If, in rehabilitating a sewage treatment plant you discover that the air compressors used in the activated sludge process are destroyed beyond repair, what action can you take to continue sewage treatment through the activated sludge plants? (Para 7-17b)

16. What is probably the most common difficulty you will encounter in the disposal of garbage and refuse in a city which has just recently been occupied? (Para 7-18a)

17. Pending rehabilitation of adequate disposal facilities, how should individual householders handle their refuse problem? (Para 7-18c(5))

18. Reliable information indicates that in the large, industrial city you are about to enter, the major, municipal electric generating facilities are severely damaged and repair parts are unavailable. What plan would you follow to try to provide minimum requirements of electric power in the shortest time? (Para 7-21a)

19. In rehabilitating electric power systems, what is the main source of supply? (Para 7-23)

20. When testing a rehabilitated transformer, what observations might you make if it is not functioning properly? (Para 7-24d)